1-1-1888

Bulletins of the U.S. Geological Survey, Volume 7. Bulletins 42-46

Recommended Citation

H.R. Exec. Doc. No. 137, 50th Cong., 2nd Sess. (1888)

50TH CONGRESS, 2d Session. | HOUSE OF REPRESENTATIVES. | MIS. DOC. No. 137.

DEPARTMENT OF THE INTERIOR

BULLETINS

OF THE

UNITED STATES

GEOLOGICAL SURVEY

VOL. VII

WASHINGTON
GOVERNMENT PRINTING OFFICE
1888

CONTENTS.

ILLUSTRATIONS.

BULLETIN No. 42.

BULLETIN No. 43.

BULLETIN No. 46.

ADVERTISEMENT.

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. xx, 338 pp. 35 pl. Price $1.15.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh, 1885. 4°. xviii, 243 pp. 56 l. 56 pl. Price $2.70.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. xiv, 288 pp. 46 pl. Price $1.75.

XII. Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. 1886. 4°. xxix, 770 pp. 45 pl. and atlas of 35 sheets folio. Price $8.40.

The following is in press:

XIII. Geology of the Quicksilver Deposits of the Pacific Slope, with atlas, by George F. Becker.

The following are in preparation:

I. The Precious Metals, by Clarence King.

— Gasteropoda of the New Jersey Cretaceous and Eocene Marls, by R. P. Whitfield.

— Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.

— Lake Bonneville, by G. K. Gilbert.

— Sauropoda, by Prof. O. C. Marsh.

— Stegosauria, by Prof. O. C. Marsh.

— Brontotheridæ, by Prof. O. C. Marsh.

— The Penokee-Gogebic Iron-Bearing Series of North Wisconsin and Michigan, by Roland D. Irving.

— Younger Mesozoic Flora of Virginia, by William M. Fontaine.

— Description of New Fossil Plants from the Dakota Group, by Leo Lesquereux.

— Report on the Denver Coal Basin, by S. F. Emmons.

— Report on Silver Cliff and Ten-Mile Mining District, Colorado, by S. F. Emmons.

— Flora of the Dakota Group, by J. S. Newberry.

— The Fossil Fishes and Fossil Plants of the Triassic Rocks of New Jersey and the Connecticut Valley, by J. S. Newberry.

BULLETINS.

Each of the Bulletins contains but one paper and is complete in itself. They are, however, numbered in a continuous series, and may be bound in volumes of convenient size. To facilitate this, each Bulletin has two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 43 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining values of troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A Catalogue of Geological Maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.

9. Report of work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary Studies, by Charles D. Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin, with Descriptions of New Forms, by R. Ellsworth Call. Introduced by a Sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 3 pl. Price 5 cents.

13. Boundaries of the United States and of the several States and Territories, by Henry Gannett. 1885. 8°. 135 pp. Price 10 cents.

14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.

15. On the Mesozoic and Cenozoic Paleontology of California, by Charles A. White. 1885. 8°. 33 pp. Price 5 cents.

16. On the Higher Devonian Faunas of Ontario County, New York, by John M. Clarke. 1885. 8°. 86 pp. 3 pl. Price 5 cents.

ADVERTISEMENT.

17. On the Development of Crystallization in the Igneous Rocks of Washoe, Nevada, by Arnold Hague and Joseph P. Iddings. 1885. 8°. 44 pp. Price 5 cents.

18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Charles A. White. 1885. 8°. 26 pp. 3 pl. Price 5 cents.

19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. 28 pp. Price 5 cents.

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. 114 pp. 1 pl. Price 10 cents.

21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. 16 pp. 5 pl. Price 5 cents.

22. On New Cretaceous Fossils from California, by Charles A. White. 1885. 8°. 25 pp. 5 pl. Price 5 cents.

23. Observations on the Junction between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point, Lake Superior, by R. D. Irving and T. C. Chamberlin. 1885. 8°. 124 pp. 17 pl. Price 15 cents.

24. List of Marine Mollusca, comprising the Quaternary fossils and recent forms from American Localities between Cape Hatteras and Cape Roque, including the Bermudas, by William H. Dall. 1885. 8°. 336 pp. Price 25 cents.

25. The Present Technical Condition of the Steel Industry of the United States, by Phineas Barnes. 1885. 8°. 85 pp. Price 10 cents.

26. Copper Smelting, by Henry M. Howe. 1885. 8°. 107 pp. Price 10 cents.

27. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1884–'85. 1886. 8°. 80 pp. Price 10 cents.

28. The Gabbros and Associated Hornblende Rocks occurring in the Neighborhood of Baltimore, Md., by George H. Williams. 1886. 8°. 78 pp. 4 pl. Price 10 cents.

29. On the Fresh-Water Invertebrates of the North American Jurassic, by Charles A. White. 1886. 8°. 41 pp. 4 pl. Price 5 cents.

30. Second Contribution to the Studies on the Cambrian Faunas of North America, by Charles D. Walcott. 1886. 8°. 369 pp. 33 pl. Price 25 cents.

31. A Systematic Review of our Present Knowledge of Fossil Insects, including Myriapods and Arachnids, by Samuel H. Scudder. 1886. 8°. 128 pp. Price 15 cents.

32. Lists and Analyses of the Mineral Springs of the United States; a Preliminary Study, by Albert C. Peale. 1886. 8°. 235 pp. Price 20 cents.

33. Notes on the Geology of Northern California, by Joseph S. Diller. 1886. 8°. 23 pp. Price 5 cents.

34. On the relation of the Laramie Molluscan Fauna to that of the succeeding Fresh-water Eocene and other groups, by Charles A. White. 1886. 8°. 54 pp. 5 pl. Price 10 cents.

35. The Physical Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1886. 8°. 62 pp. Price 10 cents.

36. Subsidence of Fine Solid Particles in Liquids, by Carl Barus. 1887. 8°. 58 pp. Price 10 cents

37. Types of the Laramie Flora, by Lester F. Ward. 1887. 8°. 354 pp. 57 pl. Price 25 cents.

38. Peridotite of Elliott County, Kentucky, by Joseph S. Diller. 1887. 8°. 31 pp. 1 pl. Price 5. cents.

39. The Upper Beaches and Deltas of the Glacial Lake Agassiz, by Warren Upham. 1887. 8°. 84 pp. 1 pl. Price 10 cents.

40. Changes in River Courses in Washington Territory due to Glaciation, by Bailey Willis. 1886. 8°. 10 pp. 4 pl. Price 5 cents.

41. Fossil Faunas of the Upper Devonian — the Genesee Section, New York, by Henry S. Williams. 1886. 8°. 121 pp. 4 pl. Price 15 cents.

42. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1885–'86. F. W. Clarke, chief chemist. 1887. 8°. 152 pp. 1 pl. Price 15 cents.

Numbers 1 to 6 of the Bulletins form Volume I; Numbers 7 to 14, Volume II; Numbers 15 to 23, Volume III; Numbers 24 to 30, Volume IV; Numbers 31 to 36, Volume V; Numbers 37 to 41, Volume VI. Volume VII is not yet complete.

The following are in press:

43. On the Tertiary and Cretaceous Strata of the Tuscaloosa, Tombigbee, and Alabama Rivers, by Eugene A. Smith and Lawrence C. Johnson. 1887. 8°. 189 pp. 21 pl. Price 15 cents.

44. Bibliography of North American Geology for 1886, by Nelson H. Darton. 1887. 8°. 35 pp. Price 5 cents.

45. Present Condition of Knowledge of the Geology of Texas, by Robert T. Hill. 1887. 8°.

46. The Nature and Origin of Deposits of Phosphate of Lime, by R. A. F. Penrose, jr.

47. Analyses of Waters of Yellowstone National Park, by F. A. Gooch and J. E. Whitfield.

48. On the Form and Position of the Sea Level, by R. S. Woodward.

49. On the Latitude and Longitude of Points in Missouri, Kansas, and New Mexico, by R. S. Woodward.

50. Invertebrate Fossils from California, Oregon, Washington Territory, and Alaska, by C. A. White.

51. On the Subaërial Decay of Rocks and the Origin of the Red Color of Certain Formations, by Israel C. Russell.

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 42

WASHINGTON
GOVERNMENT PRINTING OFFICE
1887

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

REPORT OF WORK DONE

IN THE

DIVISION OF CHEMISTRY AND PHYSICS

MAINLY DURING THE

FISCAL YEAR 1885-'86

F. W. CLARKE, Chief Chemist

WASHINGTON
GOVERNMENT PRINTING OFFICE
1887

CONTENTS.

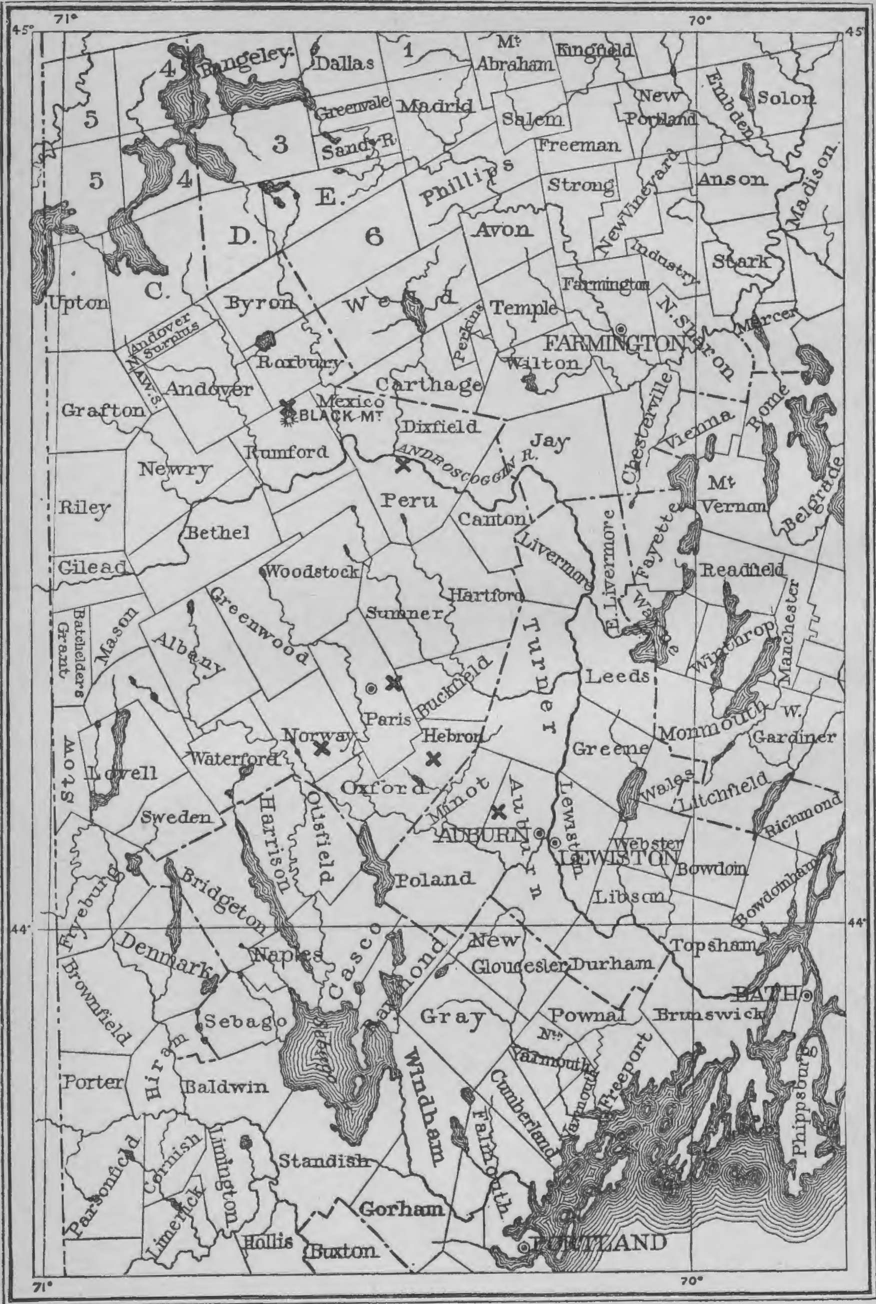
ILLUSTRATIONS.

PREFACE.

The present bulletin, like the preceding bulletins numbered 9 and 27, is intended to give a fair representation of the work done in the chemical and physical laboratories of the United States Geological Survey during one fiscal year. It covers, however, only such work as has been actually finished during the stated time, and therefore much material relative to investigations still in progress has been necessarily omitted. One paper, like two others in Bulletin 27, represents the continued co-operation of Prof. V. Strouhal, of Prague, and another bears the names of F. W. Clarke and J. S. Diller as joint authors. Although Mr. Diller is connected with another branch of the Survey, he has rendered many services to this division and has added much to the value of two of the papers herein presented.

The two papers by Dr. Gooch cover investigations which were necessary in the course of a large series of analyses of geyser waters from the Yellowstone Park. The latter are held back for the present, but will appear in a future publication. Mr. Whitfield's research also arose out of similar exigencies. In each case the existing methods of determination were unsatisfactory and not exact enough for our purposes.

F. W. CLARKE,
Chief Chemist.



MAP OF A PORTION OF WESTERN MAINE.

WORK DONE IN THE DIVISION OF CHEMISTRY AND PHYSICS IN 1885-'86.

SCIENTIFIC PAPERS.

RESEARCHES ON THE LITHIA MICAS.

BY F. W. CLARKE.

I. THE LEPIDOLITES OF MAINE.

In the western part of Maine, along a line running southeasterly from the Rangeley Lakes to a point on the seaboard between Portland and Brunswick, is a series of veins of albitic granite which are noted for the lithia micas and colored tourmalines that they contain. These localities, in the towns of Hebron, Auburn, Norway, Paris, and Rumford, are all within a narrow belt of about 40 miles in length, and with them, as a probable part of the same system, may be classed the spodumene locality in the town of Peru. The northernmost locality is that on Black Mountain, in Rumford; but a few fragments of inferior green tourmaline have been found about five or six miles farther north, in Roxbury, a fact which indicates a prolongation of the belt in that direction. Similarly, a southern extension of the belt is suggested in the region covered by the towns of Pownal, Durham, Yarmouth, and Freeport, a region from which a few specimens of lepidolite have been reported. The total width of the belt, so far as has been observed, appears to be not much over 15 miles.

In general character the several localities are much alike, although in points of minor detail they differ considerably. With the tourmaline and lepidolite, quartz, muscovite, cleavelandite, cassiterite, and amblygonite are always associated; and other minerals, to be specially noted in the separate consideration of the localities, are often found. Some of the differences are doubtless due to the fact that certain localities have been more thoroughly opened up than others, and these would probably be eliminated by more complete exploration. Other differences, however, are notable and characteristic. The accompanying map (Plate I), which shows the geographical distribution of the localities, will be of use for reference during the following discussion.

For convenience we may consider the lepidolites of the several localities separately, beginning with the northernmost and proceeding southward in regular order.

Rumford.—The Rumford locality was discovered several years ago by Mr. E. M. Bailey, of Andover, Maine, but it was not opened up until 1883. It is most easily approached from Andover and is situated on the northern slope of Black Mountain, at an estimated elevation of about a thousand feet above the base. As yet the excavations are merely superficial, although they are sufficient to show the general character of the deposit. A part of the lepidolite, which is very abundant, is fairly pure, lilac purple in color, and finely granular; but the larger portion of the mineral is coarser in structure, reddish, and thickly sprinkled with small, opaque, red tourmalines. The color of the latter is very rich, and some are found in radiated masses of considerable size; but so far no true gem material has been obtained at the locality. The appearance of the associated lepidolite and tourmaline is strikingly characteristic and resembles nothing from the other localities of the region. Green tourmaline is found quite sparingly, and so also are amblygonite and tinstone. The spodumene, however, is one of the notable features of the deposit, occurring in masses of very great size. Faces of this mineral over a meter in length can be observed at several points along the vein. At the other lepidolite localities spodumene is comparatively scarce. An analysis of the granular purple lepidolite gave Mr. R. B. Riggs the following results:

	I	II
SiO_2	51.52	51.32
Al_2O_3	25.89	26.35
Fe_2O_3	.31	
FeO	Undet.	
MnO	.20	....
CaO	.16	....
MgO	.02	....
Li_2O	4.87	4.93
Na_2O	1.18	.94
K_2O	11.00	11.02
H_2O	.88	1.02
F	5.80	5.91
	101.83	
Less oxygen	2.44	
	99.39	

In the ordinary analysis no cæsium nor rubidium could be found; but a bare trace of the the latter was shown spectroscopically in an examination of the alkalies concentrated from 150 grammes of the mineral. In all the analyses the water was determined directly by means of the

Gooch tubulated crucible. Lithia was estimated by the new method devised by Dr. Gooch and described in another part of this bulletin. The fluorine was determined by the old Berzelius process.

Paris.—The famous locality known as Mount Mica, which lies about a mile eastward from the village of Paris, was discovered in 1820 by Messrs. E. L. Hamlin and Ezekiel Holmes. Since that time large excavations have been made in search of mica and of gem tourmalines, and the locality is one of those most noted among mineral collectors. It has been thoroughly described by various writers, especially by Dr. A. C. Hamlin in his little book The Tourmaline.[1] Quite naturally, on account of the long continued explorations, the list of species found at Mount Mica is much fuller than that for any of the other deposits; and, according to Mr. S. R. Carter, who has supervised much of the excavation and made large personal collections, it embraces the following minerals: *Tourmaline*, black, green, red, blue, white, and yellow; *Beryl*, green, white, and yellow; *Quartz*, rose, yellow, smoky, and crystallized; *Garnet; Zircon; Albite*, cleavelandite; *Orthoclase; Spodumene; Muscovite; Biotite; Lepidolite; Autunite; Apatite*, green, blue, and crystallized; *Cookeite; Brookite; Childrenite; Yttrocerite; Amblygonite; Kaolinite; Halloysite; Cassiterite; Lölingite; Triphylite; Pyrite;* and *Tantalite* (?).

The lepidolite occurs both in the purple, granular form, and also broadly foliated like muscovite. The latter variety was analyzed by Mr. Riggs, and the results may well be compared with those obtained by Berwerth[2] and by Rammelsberg:[3]

	Riggs. I.	Riggs. II.	Berwerth.	Rammelsberg.
SiO_2	50.92	50.68	50.39	52.61
Al_2O_3	24.99	....	28.19	28.43
Fe_2O_3	.30	....	....	....
FeO	.23	....	....	....
MnO	Trace	....	Trace	Mn_2O_3 Trace
Li_2O	4.11	4.29	5.08	4.09
Na_2O	2.23	2.00	....	.79
K_2O	11.50	11.25	12.34	10.89
Cs_2O	Trace	....	....	....
Rb_2O	Trace	....	....	....
H_2O	1.92	2.00	2.36	.22
F	6.29	6.31	5.15	5.19
	102.49		103.51	102.22
Less oxygen	2.64		2.17	2.19
	99.85		101.34	100.03

[1] Published by James R. Osgood & Company, Boston, 1873, 12°, 107 pp.
[2] Zeit. Kryst. Min., 2, p. 523.
[3] See Third Supplement to Dana's System of Mineralogy p. 79.

Hebron.—About 7 miles southeast of Mount Mica is the well known locality in Hebron, which, however, because of legal complications in the title to the land, has been but little worked. All the exploration, so far, has been superficial; and yet many fine specimens of green and red tourmaline, cassiterite, amblygonite, cookeite, beryl, apatite, and childrenite have been obtained. The lepidolite of this locality is of the ordinary purple, coarsely granular kind, but is especially interesting on account of the fact that it has supplied chemists with considerable quantities of the rare metals cæsium and rubidium. The existence of these elements in lepidolite was first pointed out by Johnson and Allen,[1] who were working on the Hebron mineral; and yet no complete analysis of the latter seems so far to have been published.

The following results were obtained by Mr. Riggs:

	I.	II.
SiO_2	48.80	48.68
Al_2O_3	28.29	28.71
Fe_2O_3	.29	
FeO	.09	
MnO	.08	....
CaO	.10	....
MgO	.07	....
Li_2O	4.40	4.58
Na_2O	.72	.76
K_2O	12.35	12.06
Rb_2O		
Cs_2O		
H_2O	1.66	1.80
F	4.96	5.19
	101.81	
Less oxygen	2.02	
	99.79	

In this case the potassium, rubidium, and cæsium were weighed together as chlorides and the chlorine was subsequently determined. The percentages given, 12.35 and 12.06, respectively, therefore represent the actual oxides present, and not merely a computation of all as potash from the platinchloride. In the one case we have 10.34 of metal to 2.01 of oxygen, while in the second analysis we have the ratio 10.98

[1] Am. Jour. Sci. (II), XXXV, p. 94.

to 1.98. If cæsium and potassium only were present these would give by indirect calculation the following proportions of the two metals:

	I.	II.
K_2O	11.47	11.40
Cs_2O	.88	.66
	12.35	12.06

The cæsia and rubidia present, therefore, must be less than the figures given for Cs_2O.

Associated with the Hebron lepidolite there have been found specimens of red and green tourmaline, which, preserving their crystalline form, have undergone alteration into a softer mineral of an opaque, talcose appearance. Some of this material so derived from tourmaline has been supposed to be lepidolite; and, as it was possible that a study of it might be of interest, an analysis of a pink specimen, originally rubellite, was made by Mr. Riggs. The specific gravity, as determined by Mr. T. M. Chatard, was 2.87. Analysis is as follows:

SiO_2	43.90
Al_2O_3	38.71
Fe_2O_3	.58
FeO	.25
MnO	.04
CaO	.41
MgO	.05
Na_2O	1.05
K_2O	10.92
H_2O	4.25
F	None
B_2O_3	Strong trace
	100.16

These results show clearly that the alteration product is not lepidolite, but damourite, a fact which could hardly be altogether unexpected.

Auburn.—In the western part of this town, near the Minot line, there are two localities, less than half a mile apart, yielding lepidolite with the associated minerals. The one longest known is small and apparently unimportant, while the other, lying about southeast of the first, upon the farm of Mr. G. C. Hatch, has been thoroughly opened. It has yielded a large number of gem tourmalines, mostly of the paler greenish, lilac, or lavender colors, unusually fine crystallizations of apatite, and perhaps the best crystallizations of lepidolite so far known.[1] Cookeite, orthoclase, albite, cassiterite, muscovite, biotite, beryl, garnet, quartz,

[1] For a description of this locality, see G. F. Kunz, Am. Jour. Sci. (III), XXVII, p. 303.

and amblygonite are among the other species here found. The lepidolite occurs in the ordinary purple, coarsely granular form, and also in remarkable perfection as a border upon muscovite, the broad plates of the latter being practically encircled by aggregations of small crystals of the lithia mica. Some specimens of this type have also been found at Paris, but the Auburn examples are much finer than those from other localities. The accompanying illustration (Fig. 1) shows the peculiar association of the two minerals.

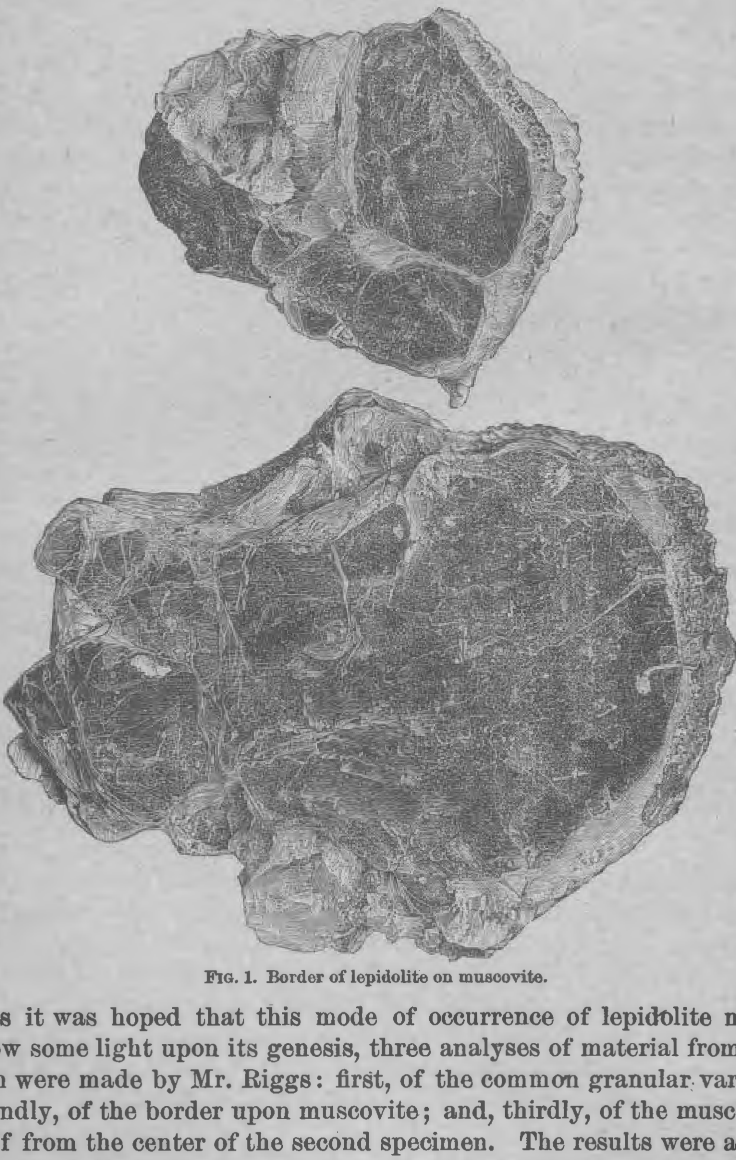


FIG. 1. Border of lepidolite on muscovite.

As it was hoped that this mode of occurrence of lepidolite might throw some light upon its genesis, three analyses of material from Auburn were made by Mr. Riggs: first, of the common granular variety; secondly, of the border upon muscovite; and, thirdly, of the muscovite itself from the center of the second specimen. The results were as follows, the lithia being determined by the old phosphate method:

	I. Granular lepidolite.			II. Border on muscovite.		III. Muscovite.
SiO_2	51.11			49.62		44.48
Al_2O_3	25.26			27.20		35.70
Fe_2O_3	.20			.31		1.09
FeO	.07			.07		1.07
MnO	.17			.55		Trace
CaO	.12			....		.10
MgO	.01			....		Trace
Li_2O	4.78	5.17		4.50	4.17	Trace
Na_2O	1.52	1.35		2.10	2.25	2.41
K_2O	10.51			8.03		9.77
Rb_2O	1.29	12.21		2.44		....
Cs_2O	.45			.72		....
H_2O	.88	1.01		1.52		5.50
F	6.57	6.67	6.60	5.45	5.78	.72
	102.94			102.51		100.84
Less oxygen	2.76			2.29		.30
	100.18			100.22		100.54

In these analyses the determinations of cæsia and rubidia are to be considered merely as rough approximations. The cæsium was separated as stannichloride, and the rubidium and potassium were computed from the amount of chlorine in the mixed chlorides of the two metals. In the oxides K_2O, Rb_2O, and Cs_2O, taken together, the actual ratio of metal to oxygen in analyses I and II is as follows:

	I.		II.
Metal	10.32	10.26	9.57
Oxygen	1.93	1.95	1.62
$(KRbCs)_2O$	12.25	12.21	11.19

Norway.—This locality, which has been but little opened, is about seven miles from Mount Mica, in a southerly direction. With the lepidolite are associated, as usual, quartz, the feldspars, the micas, cassiterite, lithiophilite, beryl, &c., and also a peculiar rose red clay, derived from some other species by alteration. Most of the colored tourmaline is of a peculiar dark oily green tint, and the lepidolite is partly of a coarsely granular white variety and partly of a brownish, very finely granular sort.

Analyses of both varieties by Mr. Riggs came out as follows:

	White.		Brown.
SiO_2	49.52	49.45	50.17
Al_2O_3	28.80		25.40
Fe_2O_3	.40		.87
FeO	.24		.45
MnO	.07		.23
CaO	.13		Undet.
MgO	.02		Undet.
Li_2O	3.87		4.03
Na_2O	.13		
K_2O	8.82	12.70	13.40
Rb_2O	3.73		
Cs_2O	.08		
H_2O	1.60	1.85	2.02
F	5.18	5.39	5.05
	102.59		101.62
Less oxygen	2.18		2.13
	100.41		99.49

The analysis of the brown variety was only partial.

The lithia was determined by the phosphate method, while, as in the case of the Auburn material, the cæsia and rubidia estimations are merely approximative. The actual ratios between metal and oxygen in the potassium group, as found in the two experiments upon the white lepidolite, are subjoined:

Metal	10.83	10.91
Oxygen	1.80	1.79
$(KRbCs)_2O$	12.63	12.70

The fact that this lepidolite is the richest of the series in these rare metals becomes doubly interesting when we remember that a beryl from the same or a nearly adjacent locality gave Penfield 1.66 per cent. of cæsia.[1]

Of the rose-red clay, previously mentioned, a partial analysis was published in Bulletin No. 9, U. S. Geol. Surv. The following complete analysis by Mr. Riggs is better, and shows, in spite of some little non-uniformity of composition in the material, that it is to be classed most definitely as cimolite:

SiO_2	66.86
Al_2O_3	22.23
Fe_2O_3	.47

[1] Am. Jour. Sci. (III), XXV, p. 28. The Hebron beryl contains 2.92 per cent.

FeO	.12
MnO	.07
CaO	.42
MgO	.33
Li_2O	.29
Na_2O	.46
K_2O	.18
H_2O	8.26
F	.06
	99.81
Less oxygen	.02
	99.79

Formula, $Al_2H_4(SiO_3)_5$.

It is not easy to determine, from the specimens at hand, from what species this clay has been derived.

DISCUSSION OF RESULTS.

The foregoing analyses of the Maine lepidolites cover several distinct types of the mineral from five different localities, and yet they indicate a very great constancy or uniformity of composition. For convenience of comparison, we may tabulate the results, using mean values whenever two determinations of a constituent have been made. Two exceptions to this rule, however, have been adopted, namely, to use the higher determinations for silica and the lower for fluorine, because of the known direction of the experimental errors in the analytical processes. Slight loss of silica, when fluorine is present, is difficult to avoid; and so also slight impurities in the calcium fluoride can hardly be eliminated. With these qualifications the analyses may be stated as follows:

	Rumford, purple.	Paris, foliated.	Hebron, granular.	Auburn.		Norway.	
				Border.	Granular.	White.	Brown.
SiO_2	51.52	50.92	48.80	49.62	51.11	49.52	50.17
Al_2O_3	25.96	24.99	28.30	27.30	25.26	28.80	25.40
Fe_2O_3	.31	.30	.29	.31	.20	.40	.87
FeO	Undet.	.23	.09	.07	.07	.24	.45
MnO	.20	Trace	.08	.55	.17	.07	.23
CaO	.16	Trace	.10	....	.12	.13	Undet.
MgO	.02	Trace	.07	....	.01	.02	Undet.
Li_2O	4.90	4.20	4.49	4.34	4.98	3.87	4.03
Na_2O	1.06	2.11	.74	2.17	1.43	.13	
K_2O	11.01	11.38		8.03	10.51	8.82	13.40
Rb_2O	....	Trace	12.21	2.44	1.29	3.73	
Cs_2O	....	Trace		.72	.45	.08	
H_2O	.95	1.96	1.73	1.52	.94	1.72	2.02
F	5.80	6.29	4.96	5.45	6.57	5.18	5.05
	101.89	102.38	101.86	102.52	103.11	102.71	101.62
Less oxygen	2.44	2.64	2.02	2.29	2.76	2.18	2.13
	99.45	99.74	99.84	100.23	100.35	100.58	99.49

With this table may be advantageously compared the following analyses of lepidolite from three foreign localities:[1]

	Rozena.		Cornwall, Rammelsberg.	Juschakova.	
	Berwerth.	Rammelsberg.		Rosales.	Rammelsberg.
SiO_2	50.98	51.32	51.70	48.92	50.26
Al_2O_3	27.80	26.00	26.76	19.03	21.47
Fe_2O_3	....	....	....	....	....
FeO	.05	....	....	....	....
Mn_2O_3	....	1.30	1.29	5.59	5.36
CaO	....	....	.40	.14	....
MgO	....	....	.24	....	....
Li_2O	5.88	3.87	1.27	2.77	4.88
Na_2O	....	.96	1.15	2.23	.54
K_2O	10.78	9.98	10.29	10.96	11.08
H_2O	.96	.57	....	....	.66
F	7.88	7.18	7.12	10.44	8.71
Cl	....	....	....	1.31	1.16
P_2O_5	.05	....	.16	....	....
	104.38	101.18	100.38	101.39	104.12
Less oxygen	3.37	3.02	2.99	4.68	3.93
	101.01	98.16	97.39	96.71	100.19

Few other lepidolite analyses are worth quoting, except possibly Cooper's analysis of the Rozena mineral, in which he found 0.24 per cent. of rubidia and a trace of cæsia.[2] The essential identity of the material from Maine, Rozena, and Cornwall is thus made clear, while the lepidolite from Juschakova is different in its large percentage of manganese, its higher fluorine, and its trace of chlorine. In the last named mineral of course the manganese replaces an equivalent amount of alumina, and the function of chlorine is the same as that of fluorine. In the other analyses, to speak in general terms, the water and fluorine vary somewhat reciprocally, suggesting the ordinary replacement of the latter element by hydroxyl. With this assumption, if it may be called so, the formula of lepidolite may be written thus:

$$Al_2(SiO_3)_3F_2LiK;$$

a formula which has long had general acceptance, but which is now put upon a surer basis by the wider range of analyses. It corresponds to the following theoretical composition:

	Calculated.		Found (Riggs).
SiO_2	49.18	SiO_2	48.80 to 51.52
Al_2O_3	27.87	Al_2O_3	24.99 to 28.80
Li_2O	4.09	Li_2O	3.87 to 4.98
K_2O	12.81	$(NaKRbC_5)_2O$	12.07 to 13.68
F	9.84	(F,H_2O)	6.69 to 8.25

[1] See Dana's System of Mineralogy, p. 315, and Third Supplement, pp. 78, 79.
[2] Pogg. Ann., pp. 113, 343.

Most of the variations from theory are no greater than we should expect to find them with material so difficult to secure in absolute purity as lepidolite. The granular structure of the species is peculiarly favorable to the presence of inclusions of foreign matter, such as albite, for example, to which latter impurity some of the soda found in the analyses is very probably due. The greatest difference is in the case of fluorine, although the foreign analyses—notably Rammelsberg's analysis of the Juschakova mineral—contain very nearly the full theoretical amount. If, however, the fluorine is present in the univalent group AlF_2, it is possibly replaceable in part by the similar group AlO, a supposition which easily accounts for all the variations. With this supposition it becomes a simple matter to write a probable structural formula for lepidolite, as follows:

$$Al \begin{cases} SiO_3 - Al{=}F_2. \\ SiO_3 - K. \\ SiO_3 - Li. \end{cases}$$

Thus the mineral is regarded as a definite substitution derivative of the normal aluminum metasilicate $Al_2(SiO_3)_3$, one atom of Al having been replaced by the three univalent factors represented above. Another view of its structure is given at the close of this paper.

II. THE IRON LITHIA MICAS OF CAPE ANN.

In the granite quarries of Rockport, Massachusetts, near the extremity of Cape Ann, there are occasional veins of feldspathic character which contain, along with the ordinary constituents of such veins, the rare minerals danalite, fergusonite, cyrtolite, amazon stone, and certain remarkable micas. One of the latter, cryophyllite, was described by Cooke in 1867,[1] who also analyzed an associated "lepidomelane," to which Dana afterwards gave the name of annite. The vein from which Cooke obtained his material was long ago blasted away or covered up, but other veins of like nature are still accessible, and from one of them the micas examined in this laboratory were obtained. They were collected for the United States National Museum by the original discoverer of the locality, Mr. W. J. Knowlton, and were, to all outward appearance, identical with the micas described by Cooke. The analyses, however, reveal notable differences between the older and the newer material and add great interest to the micas of the locality.

In the collection furnished by Mr. Knowlten two micas were clearly recognizable, the one a dark greenish black lithia mica, presumably cryophyllite, and the other a black, brilliant lepidomelane. In some specimens the cryophyllite formed a border of small crystals around the broader plates of annite, precisely as in the association of lepidolite and

[1]Am. Jour. Sci. (II), XLIII, p. 217.

muscovite at Auburn. The resemblance in this point is curiously striking, only that the Rockport specimens are less conspicuous than those from Auburn, since they lack the contrast of color by which the latter are characterized.

The lithia mica, or cryophyllite, varies considerably in external character, and three well marked types of it were selected for analysis: first, the broadly foliated, brilliant, blackish green mica, which showed no trace of alteration; secondly, a paler, dull green, less lustrous variety, apparently somewhat altered upon the surface; thirdly, an aggregation of minute six-sided prisms, so small as to give the mineral an almost granular appearance, similar to an ordinary dark green chlorite. The analyses were made by Mr. Riggs, who used the Gooch process for separating lithia and Berzelius's method for the fluorine. The results were as follows:

	Foliated.		Altered.		Granular.	
SiO_2	51.96	51.74	51.46	51.35	52.17	52.07
Al_2O_3	16.89		16.22		16.39	
Fe_2O_3	2.63		2.21		4.11	
FeO	6.35	6.29	7.66	7.60	6.08	5.90
MnO	.24		.06		.32	
CaO	.12		Trace		Trace	
MgO	.03		.17		Trace	
Li_2O	4.93	4.80	4.83	4.78	5.03	4.95
Na_2O	.92	.81	.95	.82	.60	.66
K_2O	10.66	10.73	10.65	10.65	10.54	10.42
H_2O	1.22	1.40	1.06	1.18	1.43	1.48
F	6.78	6.86	7.44	7.60	7.02	7.20
	102.73		102.71		103.69	
Less oxygen	2.86		3.11		2.95	
	99.87		99.60		100.74	

These results demonstrate the essential identity of the three specimens, but do not sharply correspond with the figures given by Cooke. In mean, using, as in the case of the lepidolites, the maximum silica and minimum fluorine determinations, they may be compared with Cooke's analysis as follows:

	Riggs.	Cooke.
SiO_2	51.86	51.49(+1.97)
Al_2O_3	16.50	16.77
Fe_2O_3	2.98	1.97
FeO	6.65	7.98
MnO	.21	Mn_2O_3 .34
CaO	.04	....
MgO	.07	.76
Li_2O	4.89	4.06
Na_2O	.79	Trace
K_2O	10.61	13.15. Tr. Rb_2O
H_2O	1.29	....
F	7.08	SiF_4 3.42. F, 2.49
	102.97	99.94
Less oxygen	2.98	
	99.99	

It will be seen at once that Cooke's mineral contains only about one-third of the fluorine found in the later analyses and that it runs notably higher in silica and alkalies. In general terms the same mineral is represented by both analyses, with the presumption as to purity in favor of the specimens examined by myself. If we assume that Cooke's material contained a slight isomorphous admixture of some other micaceous species poor in fluorine, the most important difference is accounted for.

Inasmuch as some writers have been inclined to identify cryophyllite with zinnwaldite, a comparison of the two species may be instructive. The published analyses of zinnwaldite vary widely, especially in the amounts of iron; but the older figures are subject to doubt as regards the relative proportions of ferrous and ferric oxides. Two comparatively recent analyses by Berwerth and Rammelsberg, however, agree fairly well with each other, although, compared with former determinations, they run low in iron. The comparison between the analyses is subjoined:

	Cryophyllite, Riggs.	Zinnwaldite.	
		Berwerth.[1]	Rammelsberg.[2]
SiO_2	51.86	45.87	46.44
Al_2O_3	16.50	22.50	21.84
Fe_2O_3	2.98	.66	1.27
FeO	6.65	11.61	10.19
MnO	.21	1.75	1.57
CaO	.04		
MgO	.07		.18
Li_2O	4.89	3.28	3.36
Na_2O	.79	.42	.54
K_2O	10.61	10.46	10.58
H_2O	1.29	.91	1.04
F	7.08	7.94	7.62
P_2O_5		.08	
	102.97	105.48	104.63

[1] Zeit. Kryst. und Min., II, p. 525. [2] See Third Supp. to Dana's Syst. Min., p. 79.

Reduced to empirical formulæ these analyses give two quite different ratios, which, however, do not admit of very simple expression:

Cryophyllite: $FeH_3K_3Li_4Al_4F_4(SiO_3)_{10}$;
or, $Al_2(SiO_3)_5F_2R'_6$.
Zinnwaldite: $Fe_3H_2K_4Li_4Al_8F_8(SiO_3)_{14}$;
or, $Al_4(SiO_3)_7F_4R'_8$.

The further consideration of these formulæ may be deferred until the latter portion of the paper. For present purposes they serve to show the non-identity of the two minerals.

For the lepidomelane, or annite, of Rockport, quite unexpected results were obtained. The material analyzed by Mr. Riggs was black, brilliant, broadly foliated, and apparently very pure. Upon the specimens examined some purple fluorite was visible. The water estimations were directly made with the Gooch tubulated crucible.

	Annite.		
	Riggs.	Cooke.	
SiO_2	31.96		39.55
TiO_2	3.42	....	
Al_2O_3	11.93		16.73
Fe_2O_3	8.06		12.07
FeO	30.35		17.48
MnO	.21	Mn_2O_3	.60
CaO	.23	....	
MgO	.05		.62
Li_2O	Trace		.59
Na_2O	1.54		Trace
K_2O	8.46		10.66
H_2O	4.25		1.50
F	Trace	SiF_4	.62
	100.46		100.42

It is at once evident that two entirely distinct micas are here represented, and the question is raised as to whether the Rockport granites may not contain a series of complex isomorphous mixtures. Cooke, indeed, pointed out the isomorphism of cryophyllite with the lepidomelane which he had analyzed, and showed that the lithia and the fluorine in the latter were probably due to admixtures of the former. We now see that more than two micas are involved in the problem, and the difficulty of establishing accurate formulæ for the several species becomes enormously increased. For the present, approximate formulæ only can be assigned, involving various assumptions and representing probabilities rather than complete interpretations of the facts. If we unite the groups TiO_2 and SiO_2 in our annite and regard the ferric iron as belonging partly with the alumina and as partly having been the result of oxidation from the ferrous state, we have the two following general formulæ for the two analyses:

Annite, Cooke, $R'_8Al_4(SiO_4)_5$.
Annite, Riggs, $R'_{14}Al_2(SiO_4)_5$.

For the latter, the equivalent of R' is approximately $K_2H_4Fe''_4$; and for the former it is $K_2H_2\,Fe''_2$. These values correspond to the following percentage compositions:

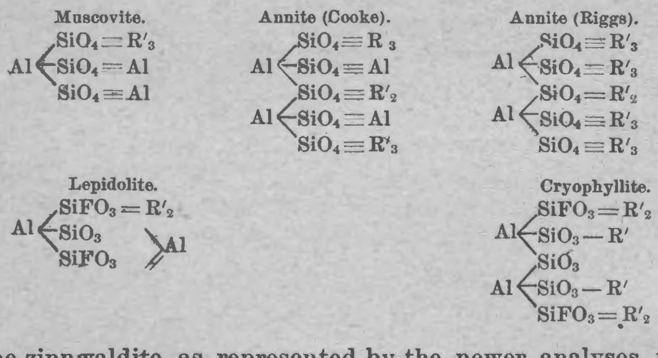
	Cooke.	Riggs.
SiO_2	39.5	36.6
Al_2O_3	26.8	12.4
FeO	18.9	35.1
K_2O	12.4	11.5
H_2O	2.4	4.4
	100.0	100.0

Attention has already been called to the fact that some specimens of cryophyllite are borders upon plates of annite, precisely as the lepidolite of Auburn is arranged about nuclei of muscovite. It accordingly becomes quite probable that a similar relation connects the two pairs of minerals, and upon that relation the formulæ so far assigned shed some light. In each case we have a mineral with metasilicate ratios implanted upon an orthosilicate, and a derivability of the one from the other is strikingly suggested. Structural analogies also appear, for in each pair we have a common type of nucleus, which may be represented as follows:

Muscovite nucleus, $Al(SiO_4)_3$.	Annite nucleus, $Al_2(SiO_4)_5$.
Lepidolite nucleus, $Al(SiO_3)_3$.	Cryophyllite nucleus, $Al_2(SiO_3)_5$.

The development of complete structural formulæ from these nuclei is rendered difficult by our ignorance of the part which fluorine plays in such compounds. In the formula previously assigned to lepidolite the fluorine is represented as combined with aluminum in the univalent group AlF_2; but a similar representation becomes difficult, if not impossible, in the case of the two iron micas. A different solution of the problem must therefore be sought, and it probably is to be found by an application of the generally recognized principle that fluorine and hydroxyl can replace each other isomorphously.

If, now, we start with orthosilicic acid $Si(OH)_4$ and regard the hydroxyl groups as successively replaceable by atoms of fluorine, we can conceive of a series of acids ranging from $Si(OH)_4$ to SiF_4; and by the aid of such a supposition many of the fluoriferous silicates may be rationally explained. For example, the acid $SiF(OH)_3$ may be considered, and its nucleus $SiFO_3$, a trivalent residue, may be applied to the discussion of the lithia micas. Upon this supposition the empirical formula for cryophyllite, $Al_2F_2Si_5O_{15}R'_6$, and the similar formula for lepidolite, $Al_2F_2Si_3O_9R'_3$, become curiously significant, especially when they are written out in contrast with two other formulæ, as in the subjoined scheme:



To the zinnwaldite, as represented by the newer analyses, no probable structure is assignable, and it is very possibly a mixture of isomorphous species. Indeed, the old analyses indicate great variability in its composition, and it needs to be more thoroughly studied, not only for itself, but also in its relations to whatever other micas may be associated with it. The matter of association can never, in the study of the micas, be safely neglected.

Although the formulæ herein assigned to annite and cryophyllite are purely provisional and approximative, at least as regards the values ascribable to R′, it may be set down as practically certain that the ratios between the sesquioxides and the silica are correctly given. These ratios are the ratios of phlogopite, with which, therefore, rather than with the lepidomelanes and biotites, the Rockport micas are chemically to be classed. Zinnwaldite is already so classed by Tschermak and others, and cryophyllite falls easily into the same category. A typical phlogopite is fairly represented by the subjoined formula:

$$\begin{array}{ll} & \mathrm{SiFO^3 = Mg} \\ \mathrm{Al} & \mathrm{SiO_4 \equiv MgH} \\ & \mathrm{SiO_4 = Mg} \\ \mathrm{Al} & \mathrm{SiO_4 \equiv MgK} \\ & \mathrm{SiFO_3 = Mg} \end{array}$$

THE MINERALS OF LITCHFIELD MAINE.

By F. W Clarke.

In Kennebec County, Maine, along and near the boundary between the towns of Litchfield and West Gardiner, are scattered many bowlders of an elæolite rock. For many years these have yielded to collectors of minerals superb specimens of blue sodalite, yellow cancrinite, and zircon; but although the parent ledge appears at several points, it seems nowhere to have been opened. In addition to the minerals already mentioned, the bowlders contain albite, lepidomelane, a black mineral resembling columbite, a flesh colored mineral which has been called indiscriminately elæolite or cancrinite, and a massive alteration product known to local collectors under the provisional name of "white sodalite." Although specimens from the locality are widely distributed in cabinets, some of the minerals seem to have been but partially described; and I have therefore thought it worth while to study them somewhat closely. The supposed columbite I have not examined, for want of material; the zircon I have omitted, since it has been sufficiently studied by Gibbs;[1] but the sodalite and cancrinite, although they had been well analyzed by Whitney,[2] I have included in my investigation, for reasons which will appear below.

ELÆOLITE.

This species occurs abundantly in Litchfield and West Gardiner in characteristic, dark gray, cleavable masses of strong greasy luster. Since it is the typical mineral of its group and as I can find no published analysis of it from this locality, the following results may have value as a matter of record:

H_2O	.86
SiO_2	43.74
Al_2O_3	34.48
CaO	Trace
MgO	Trace
K_2O	4.55
Na_2O	16.62
	100.25

[1] Pogg. Ann., LXXI, 559.

[2] Pogg. Ann., LXX, 431.

The specimen analyzed contained minute inc' ions of black mica, but not enough of them to notably affect its composition. The analysis agrees fairly well with the published analyses of elæolite from other places.

CANCRINITE.

This mineral is one of the most abundant and characteristic at the locality and varies considerably in appearance. Two analyses of it were made by Whitney, one of the yellow variety, the other of a greenish modification. I have myself seen nothing to answer to the latter description, but have selected three typical samples for investigation. They may be briefly described and indicated as follows:

A. Bright orange yellow, with strong luster and cleavage, transparent in thin fragments.

B. Dirty pale yellow, less lustrous, highly cleavable, also transparent in thin fragments.

C. Bright yellow, granular—the commonest variety.

For ease of comparison I have tabulated the analyses side by side with Whitney's, indicating his yellow cancrinite by D and his greenish variety by E. The carbonic acid determinations were made for me by Mr. R. B. Riggs, who used the Gooch tubulated crucible and collected the gas evolved directly in a potash bulb.

	A.	B.	C.	D.	E.
SiO_2	36.29	35.83	37.22	37.42	37.20
Al_2O_3	30.12	29.45	28.32	27.70	27.59
Mn_2O_3	Trace	Trace	Trace	} .86	.27
Fe_2O_3	Trace	Trace	Trace		
CaO	4.27	5.12	4.40	3.91	5.26
Na_2O	19.56	19.33	19.43	20.98	20.46
K_2O	.18	.09	.18	.67	.55
MgO	......	......	.07	......	......
H_2O	2.98	3.79	3.86	2.82	3.28
CO_2	6.96	6.50	6.22	5.95	5.92
	100.36	100.11	99.70	100.31	100.53

It will at once be observed that cancrinite A, which, from its appearance, was presumably the purest type of the mineral, is the highest of my series in carbonic acid and the lowest in water. It is also the highest in soda and alumina. Whitney's two analyses show more potash than mine, but in other respects run fairly near C, which, as I have said, represents the commonest and probably the least pure variety. But, in order to understand the variations better, we must consider the flesh colored mineral referred to in my introductory paragraph, which, as I have said, has been called indiscriminately elæolite or cancrinite, according to the fancy of the collector. It sometimes occurs in specimens of considerable size, is lustrous and cleavable, and to the eye appears perfectly homogeneous. An analysis gave the following results, the carbonic acid, as in the other cases, being determined by Mr. Riggs:

SiO_2	38.93
Al_2O_3	32.52
CaO	2.47
Na_2O	17.02
K_2O	3.23
H_2O	2.83
CO_2	2.95
	99.95

These figures plainly indicate that the mineral is a mixture of elæolite and cancrinite, but do not show whether the mixture is mechanical or due to isomorphism. To determine this point, Mr. J. S. Diller kindly undertook a microscopic examination of the material, comparing it in thin sections with the elæolite and cancrinite B, from the specimens of which portions were previously analyzed. He found the mineral to be a merely mechanical commingling of the two species, in nearly equal proportions, and later he succeeded in separating them by means of Sonstadt's solution. This fact, considered together with the apparent homogeneity of the material, renders it probable that the variations in composition of the cancrinite are due to small admixtures of elæolite, and that Whitney's specimens were rather more so contaminated than mine. Still, the entire series of cancrinite analyses are fairly concordant and confirmatory of one another. In discussing the formula of the mineral, however, analysis A will be given preference.

SODALITE.

On account of its beauty and its intense blue color, this mineral, as it occurs at Litchfield, is a favorite among collectors. It is now somewhat scarce, at least in large or compact specimens, and it ought to be carefully searched for in place. It often occurs intermingled with cancrinite, forming beautifully mottled masses, and also is associated intimately with the white, massive alteration product to be described later. The following analysis was made partly for comparison with Whitney's and partly to aid in the study of the accompanying white mineral:

	Clarke.	Whitney.	
SiO_2	37.33	37.30	37.63
Al_2O_3	31.87	32.88	30.93
Fe_2O_3	....	......	1.08
Na_2O	24.56	23.86	25.48
K_2O	.10	.59	Undet.
Cl	6.83	6.97	Undet.
H_2O	1.07	....	....
	101.76	101.60	
Deduct O=Cl	1.54		
	100.22		

In my analysis iron was not looked for, because the ignited alumina, which should have contained it if present, was perfectly white. Otherwise the analyses agree tolerably well.

HYDRONEPHELITE, A NEW SPECIES.

Intimately associated with the sodalite is the white alteration product mentioned in the last paragraph. So close is the association in fact and so similar in occurrence are the two minerals that the latter has been called white sodalite by the local collectors. Like the sodalite it is found in seams, and yields specimens as much as two centimeters in thickness; it is white, lusterless, and has the fracture of sodalite, and probably it originated from the alteration of the latter. Two specimens of it, received from two different collectors, were analyzed, with the following results:

	A.	B.
H_2O	13.12	13.30
SiO_2	38.90	39.24
Al_2O_3	33.98	33.16
CaO	.05	Trace
Na_2O	13.21	13.07
K_2O	1.01	.88
Cl	Trace	....
	100.27	99.65

The alumina carried a trace of iron, and a doubtful trace of manganese was also indicated; hardness, 4.5; fusible easily to a white enamel; soluble in hydrochloric acid and gelatinizing upon evaporation; fracture irregular, resembling that of the sodalite. In general, the mineral may be said to have the appearance of a slightly altered feldspar, minus the distinct cleavage.

These analyses left little doubt in my mind that I had a new mineral to deal with, and one belonging to the zeolite family. Such minerals are well known derivatives of the nephelite group, and thomsonite and natrolite have especially been often noted. In composition the new product differs distinctly from natrolite, but agrees in ratios approximately with thomsonite; forming, so far as chemical evidence alone goes, the soda end of a series passing through rauite up to ozarkite, the last named mineral being the nearest towards the lime end of the series. A comparison of the analyses of these elæolite derivatives is worth making, on account of its suggestiveness. The ozarkite was analyzed by Smith and Brush; the rauite, from Brevig, by Paykull.[1]

[1] Ber. deutsch. chem. Gesell., VII, p. 1334.

	Ozarkite.	Rauite.	Hydro-nephelite.
H_2O	13.80	11.71	13.12
SiO_2	36.85	39.21	38.90
Al_2O_3	29.42	31.79	33.98
Fe_2O_3	1.55	.57	....
CaO	13.95	5.07	.05
Na_2O	3.91	11.55	13.21
K_2O	....	....	1.01
	99.48	99.90	100.27

Inasmuch, however, as massive minerals, and especially those which are produced by processes of alteration, are always subject to doubt, I requested Mr. Diller to assist me with a microscopic examination of the new substance. He very kindly acceded to my request, and I subjoin an abstract of his results. In his report on it he says:

"A section was carefully prepared so as to show both the sodalite and the white lusterless mineral associated with it in such a way as to reveal their relations. The accompanying figure illustrates a small portion of the section as seen under the microscope.

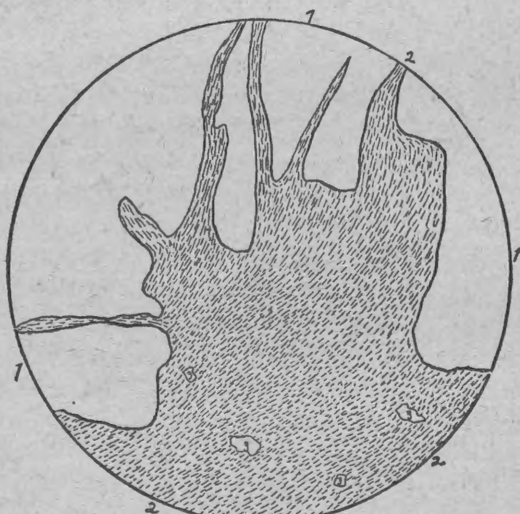


FIG. 2. Portion of thin section of hydronephelite.

"The unaltered sodalite (1) is quite irregular in form, so that the position of the section with reference to the crystallographic axes could not be determined. Although of a distinct, cobalt blue color in the small fragment, it appears colorless and transparent in the thin section, and under the microscope it is seen to contain numerous liquid inclusions. It is penetrated by many irregular fissures, which are enlarged in the process of alteration and filled with its clouded products. The extremely irregular line between the sodalite and its secondary products is well defined in transmitted light, but is even more distinct between crossed nicols from the fact that the sodalite, being isotropic, remains dark in all positions, while the other minerals are more or less brilliantly colored. The secondary products, which have clearly resulted from the zeolitization of the sodalite, are two in number. One of them forms very much the larger portion, probably nearly 90 per cent. of their total amount, and the other is embedded in the first in the form of distinct grains. Under the microscope in transmitted light the predominating mineral, which is doubtless a zeolite as shown by your analyses, is more or less deeply clouded, like decomposed feldspar. Between crossed nicols it breaks up into flaky grains, which vary considerably in the intensity of their color; some remain dark, others range through light and medium tints of red and yellow, according to the position of the section. The isotropic grains in converging light are proved to be distinctly uniaxial and positive, and the anisotropic ones, so far as can be determined, exhibit parallel extinction. It is evident therefore that the zeolite must be either quadratic or hexagonal in the system of its crystallization. Some of the grains show an indistinct striation approximately parallel to the vertical axis, but a distinct cleavage could not be discerned. In basal sections three sets of fractures could be rarely made out with sufficient distinctness to suggest that the mineral is probably hexagonal. The mode of its occurrence indicates clearly that it has resulted from the zeolitization of the sodalite, a phenomenon which has been observed in many rocks. The small grains of the other secondary mineral are so intermingled with the uniaxial zeolite as to indicate that both are derived from the sodalite. They are easily distinguished from the zeolite in which they are embedded. In transmitted light they are perfectly clear and transparent, with so high an index of refraction as to appear to rise above the surrounding mass. The grains are entirely without crystallographic boundaries, but are traversed by distinct cleavage lines. Between crossed nicols they are much more brilliantly colored than the associated zeolite, and if the section is rotated they become dark when the cleavage lines make a prominent angle (15°–33°) with the principal sections of the prisms. The mineral is certainly biaxial, and in all probability belongs to one of the two inclined systems of crystallization, but its definite determination is not practicable under the circumstances."

In view of the presence of an impurity in the new zeolite, Mr. Diller suggested a reanalysis of it to be made on carefully purified material. The purification, by means of Sonstadt's solution, he kindly undertook, determining at the same time the specific gravity of the mineral. The crude material gave him a sp. gr. of 2.263, while the zeolite was a little lighter and the embedded grains were a little heavier. After purification the coarsely powdered zeolite was carefully picked over under the microscope until Mr. Diller felt confident that the sum of all impurities could not exceed 1 per cent. The mineral, then dried at 100°, gave me the following analytical results:

H_2O	12.98
SiO_2	38.99
Al_2O_3	33.62
CaO	.07
Na_2O	13.07
K_2O	1.12
	99.85

These figures confirm the previous analyses and show that the impurity which vitiated them must have been small in amount and similar in composition to the new zeolite. The latter, I think, may be considered as fairly well established, and its formula may be written $Al_3(SiO_4)_3 Na_2H,3H_2O$, which requires, water, 13.76; soda, 13.54; alumina, 33.41, and silica, 39.29. This composition and the manifest relations of the mineral to nephelite, the parent member of the group, naturally suggest for it the name *hydronephelite*, which seems to be both appropriate and descriptive. Chemically, as I have already observed, the species approximates to a soda thomsonite, but optically it appears to be quite different. This fact suggests the desirability of a careful microscopic re-examination of all the other massive zeolitic alterations of elæolite which, on analytical grounds, have been referred to the thomsonite series. Hydronephelite, indeed, is directly derived from sodalite, but the latter itself probably originated from elæolite; so that the new species may quite properly be considered along with the other zeolites which were previously mentioned. The fact that it contains more potassium than the sodalite is noteworthy and calls for an explanation which I am unfortunately not prepared to offer.

ALBITE AND LEPIDOMELANE.

The albite of Litchfield, which appears to be associated with other undetermined feldspars, is mostly in obscure masses. Occasionally a fragment is found with a translucent cleavage surface one or two centimeters broad. Such a specimen was partially analyzed, giving H_2O 0.52, SiO_2 66.39, Al_2O_3 19.69, K_2O 0.99, Na_2O 10.17. These figures serve only for complete identification of the species.

The lepidomelane exists abundantly in the elæolite rock, but mostly in small black scales. Sometimes tolerably large plates of it are found, black and brilliant, decidedly brittle, and apparently affected by alteration. An analysis gave the following results. The iron determinations were made by Mr. Riggs:

H_2O	4.62
F	None
TiO_2	None
SiO_2	32.09
Al_2O_3	18.52
Fe_2O_3	19.49
FeO	14.10
MnO	1.42
MgO	1.01
K_2O	8.12
Na_2O	1.55
	100.92

This analysis is noteworthy on account of the extremely low percentage of silica, which is approached, so far as I can ascertain, only in an analysis by Rammelsberg of a black mica from Brevig. The ratio between silicon and oxygen is nearly 1 to 5, which agrees with no known formula. My results make it extremely probable that the mica is a mixture and that it has undergone an alteration tending toward the ultimate development of some chloritic species. Still it deserves, as also do the feldspars of the locality, a more thorough examination.

DISCUSSION OF FORMULÆ.

In attempting to discuss the formulæ of cancrinite, sodalite, and hydronephelite, certain points should be carefully borne in mind. First, the three species must be considered, not independently, but relatively to one another, for all the evidence indicates for them a common origin. That origin is from the first member of the group, elæolite or nephelite, the empirical formula for which has been finally fixed by Rauff.[1] In partially rational form it may be written $Na_8Al_8(SiO_4)_7(SiO_3)_2$, ignoring the small replacement of sodium by potassium, which has been shown by synthetic investigations to be non-essential. Not only does the mode of occurrence and association of the minerals point to community of origin, but the same conclusion is emphasized by the experiments of Lemberg[2] upon the artificial alteration of silicates. When elæolite from Fredriksvärn was digested one hundred and eighty hours with a solution of sodium carbonate, a partial transformation into a *soda* cancrinite was effected, while a digestion of six months with a caustic soda solution containing sodium chloride gave a product identical in composition with sodalite. Many such experiments were tried by Lemberg, yielding a large class of similar results. His method of procedure probably did not give absolutely pure or definite compounds, and yet his researches

[1] Zeitschr. Kryst. und Min., II, p. 445.
[2] Zeitschr. deutsch. geol. Gesell., XXXV, p. 557, 1883.

furnish evidence of great value in discussing the chemical structure of many minerals.

The taking up of sodium chloride by elæolite, both in the dry and in the wet way, has also been observed by Koch.[1] The easy alterability of elæolite, therefore, may be regarded as a point thoroughly established and to be taken into account in all discussion of it and its congeners.

If we compare the published analyses of cancrinite from different localities we shall find that they vary in two ways. First, there are variations which are probably due to admixtures of elæolite, such as I have shown to occur at Litchfield; and, secondly, the ratio between the lime and the carbonic acid ranges between rather wide limits. In the cancrinite from Miask, the two are about equivalent, while the Litchfield mineral contains only half enough calcium to saturate the carbonic acid. The lime and soda, however, vary reciprocally, so that when one is high the other is low; and, furthermore, the experiment quoted from Lemberg goes to show that a cancrinite may exist containing no lime whatever. If this conclusion be correct, then the carbonic acid of the mineral must be represented as linked with aluminum, a supposition which finds some justification in the existence of the rare species dawsonite. The function of water in cancrinite remains doubtful; if it be regarded as water of crystallization, the formula of the residue becomes less easy to write intelligibly; but, if it forms a part of the atomic structure, it is almost necessary to represent the carbonic acid as orthocarbonic in the group CO_4. This mode of consideration, as will appear later, leads to a simple general formula for cancrinite, covering all variations in composition except such as are due to impurity and correlating the mineral with the allied species sodalite and nosean. For the Litchfield mineral the following special formula may be written, giving the theoretical composition in the column below: $Al_8(SiO_4)_8(CO_4)_2CaNa_8H_6$.

	Found.	Calculated.
SiO_2	35.83 to 37.22	35.9
Al_2O_3	28.32 to 30.12	30.6
Na_2O	19.33 to 19.56	18.6
CaO	4.27 to 5.12	4.2
CO_2	6.22 to 6.96	6.6
H_2O	2.98 to 3.86	4.1
		100.0

In this case the water as found is slightly lower and the soda slightly higher than the calculated values, which is probably ascribable to the mutual replaceability of sodium and hydrogen.

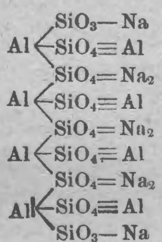
[1] Neues Jahrb., Beil. Bd. I, p. 143, 1881.

The formula commonly accepted for sodalite, and the one which is certainly the simplest, is that deduced by Bamberger[1] from his analysis of the mineral from Tiahuanuco. Written empirically, this formula is $Na_5Al_4(SiO_4)_4Cl$, which requires considerably less chlorine than has ordinarily been found in the species. In Bamberger's analysis, as finally corrected, he obtained 5.54 per cent. as against nearly 7 per cent. in Whitney's determinations. The difference he ascribes to silica in the chloride of silver, as weighed by other analysts; and yet in my own estimation every care was taken to eliminate such impurity, and my results confirm the older figures. Still, both figures have theoretical interest, as will be seen further on; and I am inclined to believe that the Bolivian mineral was more nearly typical than that from Litchfield. To the latter we may assign the empirical formula $Na_9Al_7(SiO_4)_7Cl_2$, which is directly derivable from the formula for nephelite and which agrees quite sharply with the analyses.

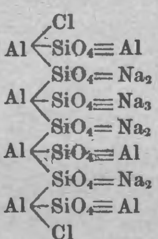
We now have three empirical formulæ ready for comparison side by side, as follows:

Nephelite	$Al_8(SiO_4)_7(SiO_3)_2Na_8$
Cancrinite (Litchfield)	$Al_8(SiO_4)_8(CO_4)_2CaNa_8H_6$
Sodalite (Litchfield)	$Al_7(SiO_4)_7Cl_2Na_9$.

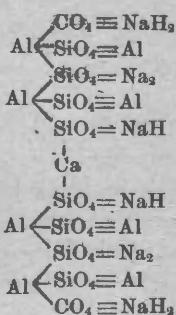
These may easily be put into structural form by an application of the principle suggested in a former paper,[2] that orthosilicates containing aluminum are to be represented as substitution derivatives of the normal salt $Al_4(SiO_4)_3$. The latter contains the fundamental nucleus $Al(SiO_4)_3$, which appears to be capable of a sort of polymerization, and which forms the basis of the subjoined symbols:



Nephelite.



Sodalite.



Cancrinite.

Now, although these formulæ fit the analyses and express a structural similiarity of type, two of them are capable of a further generalization. Remembering the reciprocal variations between soda and lime in different cancrinites and the fact that a soda cancrinite is quite pos-

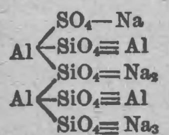
[1] Zeitschr. Kryst. und Min., V, p. 581.

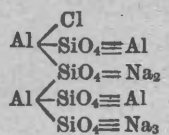
[2] Topaz from Stoneham, Maine, Bull. U. S. Geol. Surv. No. 27.

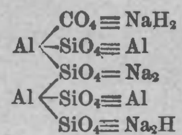
sible, we may write the following general formula for that species: $Al_4(SiO_4)_4CO_4Na_5H_3$; which requires

SiO_2	35.8
Al_2O_3	30.4
Na_2O (partly replaceable by CaO)	23.1
CO_2	6.6
H_2O	4.1

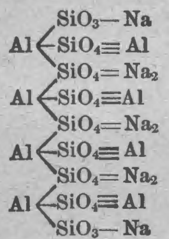
Comparing this with Bamberger's sodalite formula, and with the generally accepted formula for nosean, we have this remarkable series of structural expressions:

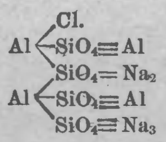

Nosean.

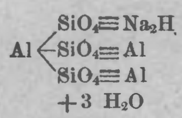

Sodalite.


Cancrinite.

The formula of hauynite of course reduces to the same type, and so also, probably, does that of microsommite. Hydronephelite has a still simpler formula, which, however, includes three molecules of water of crystallization. It may be advantageously compared in series with its parent minerals, in which case we have the following set of structures:


Nephelite.


Sodalite.


Hydronephelite.

These formulæ express with decided clearness the natural order of transition from one species to another. The alteration of a mineral necessarily involves the passage from a less stable to a more stable condition; and in this instance we observe precisely that state of affairs. From a quite complex and therefore easily disturbed molecule, through an intermediate, simpler compound, we pass to one which is simplest of all, and hence presumably the most stable. I do not deny that such formulæ are subject to criticism and that possibly the advance of knowledge may brush them to one side; and yet I feel justified in claiming that they have some real value in the co-ordination of observed facts, and that, through their singular suggestiveness, they assist in the prosecution of research.

TURQUOISE FROM NEW MEXICO.

BY F. W. CLARKE AND J. S. DILLER.

At Los Cerillos, New Mexico, about twenty-two miles southwest of Santa Fé, are mines of turquoise which have been worked for centuries. The locality has been repeatedly described[1] from archæological and geological points of view; but, so far as we are able to ascertain, the turquoise itself has never been fully analyzed, nor has it been subjected to complete microscopic study. Having at our disposal a very full suite of specimens, collected during the summer of 1885 by Maj. J. W. Powell, Director of the United States Geological Survey, we have thought it desirable to investigate the subject more thoroughly, and to present our results in such a form as to render them readily comparable with the published data concerning turquoise from other localities.

The turquoise occurs embedded in its matrix, sometimes in nodules, oftener in seams or veins. It varies in color very widely, ranging from a pure sky blue through many shades of bluish green and apple green to dark greens which show no blue whatever. The dark green nodules often shade off to nearly white at the center, sometimes resembling in structure, as Blake has observed, certain varieties of malachite. Many of the specimens are seamed or streaked by limonite, which has been derived from accompanying pyrite; and the latter mineral occasionally is found, bright and unaltered, inclosed completely in masses of clear blue turquoise.

For analysis, three samples of turquoise were selected, representing, as nearly as possible, the most definite types of the mineral. They may be summarily described as follows:

A. Bright blue, faintly translucent in thin splinters.

B. Pale blue, with a slightly greenish cast, opaque and earthy in luster, and of sp. gr. 2.805. Blake gives the density from 2.426 to 2.651 for the green variety.

C. Dark green, opaque.

[1] W. P. Blake, Am. Jour. Sci. (II), XXV, p. 227, 1858. J. S. Newberry, Report of the Exploring Expedition from Santa Fé to the Colorado, &c., 1859 (Macomb's Expedition). B. Silliman, jr., Am. Jour. Sci. (III), XXII, p. 67, 1881.

	A.	B.	C.
H_2O	19.80	19.60	18.49
Al_2O_3	39.53	36.88	37.88
Fe_2O_3	......	2.40	4.07
P_2O_5	31.96	32.86	28.63
CuO	6.30	7.51	6.56
SiO_2	1.15	.16	4.20
CaO	.13	.38	Undet.
	98.87	99.79	99.83

Analysis A is not quite complete, for enough material could not be obtained without the destruction of too valuable specimens. The silica in it was due to traces of admixed rock, from which the material could not well be perfectly freed. C, however, was free from rock, and the silica in it must be accounted for otherwise. Silliman reports the turquoise as containing 3.81 of copper, which corresponds to 4.78 of CuO, but he gives no other quantitative data.

In attempting to discuss these results, it will be well to compare them with three other published analyses of turquoise from different localities. First, we have the figures given by Church[1] for the well known variety from Persia; secondly, the analysis by G. E. Moore[2] of turquoise pseudomorphous after apatite, from Taylor's Ranch, Fresnó County, California; and, thirdly, Nikolaieff's[3] data concerning the mineral from Karalinsk, in the Kirghiz Steppes. These analyses may be tabulated as follows:

	Persia.	California.	Karalinsk.
H_2O	19.34	19.98	18.60
Al_2O_3	40.19	35.98	35.79
Fe_2O_3	....	2.99	3.52
FeO	2.21	....	....
MnO	.36	....	....
CuO	5.27	7.80	7.67
P_2O_5	32.86	33.21	34.42
	100.23	99.96	100.00
Sp. gr	2.75	2.798, 2.815	....

These analyses, leaving temporarily out of account that of the dark green variety, agree well with one another in their atomic ratios. Divid-

[1] Church, Chem. News, 10, p. 290; Dana's Syst. Min., p. 581.
[2] Zepharovich and Moore, Zeitsch. Kryst. und Min., 10, p. 240.
[3] In a paper by Kokscharoff, Neues Jahrb., 1886, I, Ref., 10.

ing the percentages by the proper molecular weights and treating the bases together, the following ratios appear:

	Total base.	P_2O_5.	H_2O.
New Mexico, A....	.468	.225	1.100
New Mexico, B....	.479	.231	1.089
Persia............	.492	.231	1.075
California.........	.470	.234	1.110
Karalinsk.........	.470	.242	1.033

In each case the base stands to the acid in a ratio very slightly in excess of two to one, and that excess may fairly be accounted for upon the supposition that it represents a trifling admixture of limonite. The water is present in a proportion a little under that of five molecules to one of phosphoric acid, the variation here being due to differences in the percentages of copper. If we calculate the amount of phosphoric acid necessary to satisfy the alumina and then reckon the phosphate so obtained as requiring five molecules of water, we shall have left over a quantity of copper, acid, and water corresponding to a very simple formula, and the turquoise will appear as a variable mixture of the two following salts:

$$2\ Al_2O_3,\ P_2O_5,\ 5\ H_2O$$
$$2\ CuO,\ P_2O_5,\ 4\ H_2O$$

In the Californian turquoise the analytical results fit these formulæ quite sharply and give the ratio between the two compounds as approximately four to one. The first formula may be regarded as that of normal turquoise, and may be written in rational form, halved, as

$$Al_2HPO_4(OH)_4$$

The copper salt, to which the mineral owes its color, is to be considered merely as an impurity, a view which is emphasized by the analysis of the dark green turquoise C. In the latter case the same ratios apply, modified by the presence of silica, which is nearly sufficient to form with the copper a normal metasilicate, similar to if not identical with chrysocolla. This silicate, with whatever blue tinge of color it might have, affected by the yellow or brown of the iron present, probably gives the turquoise its green hue. It is exceedingly probable that the purity of tint in gem turquoise is due to the copper salt alone and that degradations of the color towards green are ascribable to admixture of salts of iron. It is noteworthy that of the three turquoises analyzed the bluest contains the lowest percentage of copper. This could hardly be the case were not the colors of the other samples modified by some impurities, and compounds of iron would naturally produce an effect in the observed direction.

Sections of the three varieties of turquoise were studied under the microscope and found to be of essentially the same character. Although deeply colored in the hand specimens, the thin sections appeared almost clear and transparent. Between crossed nicols the deep blue and green forms were seen to be composed of minute grains or short, thick fibers, but in the paler varieties the fibrous structure was more pronounced. The optical properties of both grains and fibers are the same throughout. They are all weakly doubly refracting, but have a rather high refractive index. The finely granular portions have a pale bluish aggregate polarization, less intense than that of chlorite, but when the mineral is distinctly fibrous it polarizes like some forms of serpentine with light colors of the first order. The fibers are generally somewhat bent and interwoven, but lie approximately in the same direction. Each fiber becomes dark when parallel to the principal section of either of the crossed nicols, indicating that they must crystallize according to the quadratic, hexagonal, or rhombic system, instead of in one of the inclined systems, as was the case with the fibers studied by Bücking[1] in the turquoise of Fresno County, California.

A section was prepared of a distinct vein of pale green turquoise, which showed that the fibrous structure is directly across the vein perpendicularly to its walls. Small fissures, running into or across the veins, have the fibers of turquoise arranged perpendicularly along their sides, just as serpentine arranges itself along fissures in olivine. Sometimes the fissures are minute and curved; but the resulting arrangement does not simulate the radial fibrous or spherulitic structure described by Bücking[2] as found in the turquoise of California, Nevada, and elsewhere.

The perpendicular arrangement of the turquoise fibers along fissures crossing the vein indicates that the mineral may have been derived from the alteration of another substance with which the vein was formerly filled. We would suppose, of course, that the original vein material was itself a phosphate; and the only one after which turquoise is known to be pseudomorphous is apatite, a species which not infrequently occurs in veins. The opinion that the turquoise has resulted from such an alteration is favored by the presence of other alteration products, to be noted in considering the composition of the country rock in which the turquoise is found. It is also suggested by Hermann's analysis of blue Oriental turquoise, in which the equivalent of 3.41 per cent. of calcium phosphate was actually determined.[3]

The rock in which the veins of turquoise occur is described by Blake as "a granular porphyry, yellowish, gray, or white in color, porous and earthy in texture. It decomposes rapidly by weathering and very much resembles a sandstone." In the collection made by Major Powell there

[1] See paper by Zepharovich and Moore, Zeitschr. Kryst. und Min., 10, p. 240, already cited.

[2] Zeitschr. Kryst. und Min., 2, p. 163.

[3] See Dana's Syst. Min., p. 581.

are several good examples of the rock penetrated by the turquoise. It is a fine grained, reddish, feldspathic rock, mostly fresher than that described by Blake, and it has a microgranitic aspect. It contains numerous particles of biotite and pyrite, with stainings of oxide of iron. The hand specimens look as though they had been crushed, and the fissures thus formed so filled as to produce irregular veins and nodules. The veins are small and mostly composed of turquoise, in which are embedded a few scales of biotite, particles of pyrite, and considerable quartz and oxide of iron. Scales of biotite are found abundantly in the iron stained cavities, as well as in the solid portions of the rock. Some specimens of rock, containing much pale blue turquoise of earthy texture, have been completely kaolinized, and a partial analysis of the kaolin gave the following results:

H_2O	12.88
SiO_2	52.38
$Al_2O_3+Fe_2O_3$	33.49
P_2O_5	None
MgO	1.17
CaO	Trace
	99.92

Although the mineral itself was white, the alumina from it was distinctly reddish with the iron.

Under the microscope the rock is seen to be composed chiefly of feldspar, with a considerable amount of biotite, epidote, pyrite, and limonite, and some amorphous substance. It is somewhat microgranitic in structure, and the irregular interlocking grains of feldspar vary in size from .01 to .8^{mm} in diameter. Most of them are considerably kaolinized, so as to appear cloudy in ordinary light; but between crossed nicols the original outlines of the grains become more distinct. Their optical properties indicate that the feldspar is orthoclase, an opinion which is fully borne out by the subjoined analysis of the rock, which shows a remarkably large proportion of potash:

H_2O	3.28
SiO_2	56.68
Al_2O_3	16.62
Fe_2O_3	6.50
P_2O_5	.73
MgO	.79
CaO	.59
CuO	Trace, undet.
MnO	1.02
FeS_2	2.21
K_2O	11.18
Na_2O	1.03
	100.63

The porphyritic crystals are generally Carlsbad twins with irregular outlines. There are occasionally small grains of fresh, transparent plagioclase, which has evidently resulted from alteration.

The biotite of the rock occurs in noteworthy quantities, but is very unequally distributed. It is frequently aggregated in groups of scales and may be seen most abundantly in small cavities. It sometimes occurs intimately associated with the turquoise, but unlike the latter it is one of the primary minerals. The small quantity of quartz present is a secondary product, so intimately associated with turquoise as to suggest their genetic connection. Pyrite is scattered rather uniformly throughout the rock in small cubical crystals easily seen in the hand specimen. They are sometimes altered to limonite, but in other cases they have been completely replaced by pseudomorphs of epidote. The specimen of rock which was subjected to analysis probably contained an amount of pyrite rather greater than the average.

One of the most important constituents of the rock, because of its very close association with the turquoise, occurs in the form of bright yellow grains. They are not distinctly pleochroic, but have a high refractive index, with strong double refraction, and give brilliant aggregate polarization. The particles are usually very small and grouped together in irregular compound grains, so as to suggest nothing of crystallographic form. In several cases, however, elongated simple grains show inclined extinction, which indicates that the mineral must be either monoclinic or triclinic in crystallization. Judging not only from the properties enumerated, but also from the percentage of lime in the rock, this mineral is in all probability epidote. It is evidently connected genetically with the turquoise, for it is almost uniformly found upon the border of the latter and is most abundant in its neighborhood.

Concerning the origin of the turquoise bearing rock, it may be stated that Professors Newberry and Silliman, both of whom studied it in the field, regard it as eruptive and probably of Tertiary age. The occurrence of this veritable orthoclase rock in the West is of special interest from the fact disclosed by recent investigations that in many of the rocks previously described as trachytes the predominating feldspar is plagioclase.

The very small size of the veins and their limited distribution show that the turquoise is of local origin and emphasize the idea that it has resulted from the alteration of some other mineral. In addition to the evidence already cited to show that the turquoise has been derived from apatite, we have the fact that epidote, a lime bearing mineral, is present as a secondary product. The oxidation of pyrite may have had something to do with initiating the process of alteration and the alumina of the turquoise was probably derived from decomposing feldspar. The latter suggestion was made by Silliman, who also examined microscopic sections of the rock and reported apatite as present. No apatite, however, could be seen in the specimens examined by us. A search for it at the locality would certainly seem to be desirable.

THE GNEISS DUNYTE CONTACTS OF CORUNDUM HILL, NORTH CAROLINA, IN RELATION TO THE ORIGIN OF CORUNDUM.

By Thomas M. Chatard.

The associations of corundum with the olivine or dunyte rocks of Western North Carolina and the adjacent portions of South Carolina and Georgia have been often described,[1] but, having had an opportunity during the summer of 1884 to visit a few of the typical localities and to collect specimens of the associated rocks, the results of my chemical examination of some of the latter are here given, as possibly affording some data for the solution of the problem of the origin of corundum.

The names given in this paper to the various rocks and minerals, unless analyses or authorities are given, must be considered as only approximately correct. By chlorite is meant all the varieties of green, foliated, hydrous, aluminous magnesian silicates met with in connection with dunyte, while the whole series of brown and yellow foliated minerals are called vermiculites. Under the heads of enstatite, talc, &c., are grouped a number of minerals of similar appearance, many of which may prove, on examination, to have compositions differing widely from that of the species under which they are placed.

In making the analyses, the silica, after being ignited over the blast lamp to constant weight, was treated with hydrofluoric acid and the residue deducted, while the alumina iron precipitate was, after ignition to constant weight, fused with sodic bisulphate, and silica, if present,

[1] C. U. Shepard, Am. Jour. Sci. (III), IV, pp. 109, 175, 1872,
J. L. Smith, Am. Jour. Sci. (III), VI, p. 180, 1873.
F. A. Genth, Am. Phil. Soc., Sept. 19, 1873, July 17. 1874.
J. P. Cooke, Proc. Am. Acad., Vol. IX, pp. 48, 49, 1874.
C. W. Jenks, Quar. Jour. Geol. Soc., XXX, pp. 303-306, 1874.
W. C. Kerr, Geol. N. C., I, p. 64, Supplement.
C. D. Smith, Geol. N. C., I, Appendix D, pp. 91-97; II, pp. 42, 43, 1881.
R. W. Raymond, Trans. Am. Inst. Min. Eng., VII, pp. 83-90, 1878.
A. A. Julien, Proc. Bos. Soc. Nat. Hist., XXII, pp. 141-149, 1883.
M. E. Wadsworth, Mem. Mus. Comp. Zoöl., Lithological Studies, pp. 118, 119, 1884.
T. S. Hunt, Trans. Roy. Soc. Can., Vol. II, Sec. III, §§ 37, 38, 1884.
T. M. Chatard, Mineral Resources U. S., 1883-'84, pp. 714-720, U. S. Geol. Survey, Washington, 1885.

separated. Double precipitation was always employed and the precipitates were carefully tested.

THE LOCALITIES.

The principal southern mining localities for corundum are at Corundum Hill, Macon County, North Carolina, and at Laurel Creek, Georgia, 26 miles southeast of the former. Both are owned and worked by the Hampden Emery Company, under the direction of Dr. H. S. Lucas, to whom I am indebted for every desired facility and for a very warm and intelligent interest in my work.

The two localities are alike in respect to the occurrence of the corundum. In both, the mineral is found in chlorite and vermiculite lying between hornblende gneiss and altered dunyte. At Laurel Creek the open cut in which the corundum is mined runs east 10°–20° north, following the course of the veins, the mine being situated on the north bank of Laurel Creek, at the base of a high hill. On the south bank and in the bed of the creek, hornblende gneiss is the country rock, succeeded as we go northwardly by enstatite, talc, and allied minerals. The corundum first met with occurs in what is locally known as the "sand vein," which is composed of chlorite and vermiculite carrying more or less corundum, usually in small crystals and fragments. The chlorite in the upper portion of this vein was much disintegrated, the mass falling readily to pieces, allowing of the easy removal of the corundum, but at the time of my visit it was very compact and tough and of little value. The sand vein is succeeded by a so-called "horse" of steatite, on the other side of which is the vein of "block corundum." This is a vein of vermiculite containing masses of corundum sparingly mixed with chlorite and vermiculite and frequently of great size, several having been obtained of at least 5,000 pounds in weight. One mass which I saw must have weighed at least a ton. The north wall of the block vein is a smooth wall of "indurated talc" and steatite, which gradually passes into altered but still hard dunyte. Indeed, the difference between this place and Corundum Hill is in no respect more marked than in the greater hardness and toughness of the corundum bearing rocks and in the apparent concentration of the corundum into large masses with but little evidence of crystallization. At the westerly end of the cut is a vein of decomposed white material shown by analysis to be an altered soda lime feldspar. In this I did not find any corundum, but I was told that it was occasionally found in this rock.

The Corundum Hill mine is situated on a ridge which runs in the northeast and southwest direction characteristic of this section, the dunyte outcrops being on the crest, and apparently surrounded on all sides except towards the east by hornblende gneiss. On the east side mica schist[1] takes the place of the gneiss, and it is on the eastern side

[1] Probably damourite schist; cf. Am. Acad., 1874, by F. A. Genth, "Damourite."

of the dunyte that the so-called "sand vein" is found. This is a vein-like mass of brown vermiculite in small scales containing an abundance of small crystals of corundum, which are usually brown in color and often broken into fragments. At the time of my visit the nearly perpendicular vein was about 6 feet wide and was worked by hydraulic washing through an open cut about 30 feet deep. The easterly wall of this vein is the mica schist very much decomposed, while on the western side we find enstatite, next vermiculite mixed with chlorite, then talc, which in turn gives place to nodules of more or less altered dunyte.

The specimens of corundum crystals for which this locality is so celebrated have all been found on the westerly side of the dunyte, and, so far as I have seen or could find out by inquiry from the owners and the miners, only on or near the lines of contact between the gneiss and the dunyte. The dunyte is sometimes, as stated by Julien in the paper cited, "interbedded with the hornblende gneiss in layers 1 to 6 meters in thickness. This was shown by a cross-section of the beds on the north side of the dunyte deposit at the Jenks Mine (Corundum Hill), near Franklin, in Macon County. Although the dunyte is thus inclosed in or interbedded with the hornblende gneiss, the latter was never observed to be enveloped by the dunyte."

The origin of the dunyte, whether igneous or sedimentary, and, if the latter, whether mechanical or chemical, is a disputed question which has been ably discussed in the list of papers already given, and upon this point I am not able to give any further information of value. Leaving out the question of the origin of the dunyte, it appears very much like a dike or dike series, portions of which have been forced into the adjacent country rock without completely severing the connection with the main mass.

In its present condition it forms irregular spheroidal masses, sometimes several meters in diameter, most of which are much fractured and altered, the fracture seams being filled in with brown or yellow, clay-like, magnesian silicates, while the surface is also converted into a similar material which, when dry, has a strong tendency to peel off in semiconchoidal plates. In this form of alteration the mass of the nodule is still rather hard, but frequently the nodules are cased with talc, $10-20^{cm}$ in thickness and quite tough; when, however, this casing is pierced through, the interior is found to consist of a soft, yellow, ocherous material, into which a rod can be forced with comparative ease for a foot or more; towards the center of the nodule the material is often harder, being apparently less thoroughly decomposed.

The gneiss along the lines of contact is much decomposed, preserving its laminated structure but becoming a friable mass of reddish and brownish gray grains of quartz and scales of altered mica, with whitish nodules irregularly disseminated through it. Several contact sections from gneiss to dunyte were examined, and samples taken as the character of the formation seemed to change. Of these the results of the chemical examination of one series is given, as it is typical of them all, the variations in the others being due, apparently, only to differences in the relative proportions of the same general classes of minerals.

DESCRIPTION OF THE SECTIONS.

These sections were all taken in an open cut which starts from a point near the corundum mill and runs into the hill in a southeast direction. In this cut the exposures were clearest, the banks in most of the other cuts being more or less covered, either by caving or by débris piled against them in the course of the mining operations.

In going up the cut the walls were found to consist in most part of the material which I have called altered gneiss, with occasional masses of dunyte very much altered and showing the characteristic chloritic minerals. The cut at the upper end widens out immediately after passing through a belt of gneiss which crosses it with a northeast, southwest strike and a dip which is apparently eastward, but is nearly perpendicular. This rock can be traced northeast for some distance, but is then covered by mining débris, though Dr. Lucas informed me that it continued without an apparent break through that portion of the ground. Beyond the rock piles it can be traced to the main body in the higher part of the hill.

On the east side of this gneiss and on the north side of the cut we have the following sequence:

Section A.

A 1. Altered gneiss, becoming somewhat vermiculitic as it approaches A 2.
A 2. A narrow band of greenish chlorite.
A 3. A 6 inch seam of vermiculite.
A 4. Soft, yellow, magnesian clay.
A 5. A narrow seam of very impure chalcedony, stained red.
A 6. More yellow clay.
A 7. A rather hard casing, brownish yellow in color, inclosing
A 8. A large nodule of dunyte, much altered, with seams filled with soft clay and harder material of the same kind, while the comparatively hard brown yellow dunyte (A 8) has running through it small seams of
A 9. A mineral similar to enstatite.

Section B.

On the opposite side of the cut a section, B, starting from the same gneiss, shows —

B 1. Altered gneiss, like A 1.
B 2. About 2 feet (60^{cm}) of yellowish, micaceous, and quite rotten material.
B 3. About 30^{cm} of fine, scaly, brown vermiculite.
B 4. A band of foliated, compact, bright green chlorite stained bright red in places with ferric oxide or an iron clay.

B 5. Enstatite, gray in color and quite hard.

B 6. Yellow clay similar to A 6, and inclosing

B 7. Much altered but still rather hard dunyte, the casing on the other side being chlorite.

The corundum, when it occurs, is found in A 3 and B 3 and is much fractured.

Section C.

At about 10 meters northeast from A the Section C was made and gave the following series:

C 1. Altered gneiss, containing, distributed irregularly through it,

C 2. Harder nodules, very silicious; the gneiss gradually changing into

C 3. A scaly, brownish material, followed by

C 4. A soft, friable, yellowish white kaolin, intermixed with

C 5. A reddish brown, micaceous mineral, followed by

C 6. A seam of a small foliated, brownish yellow mineral which disintegrates easily, falling into small scales.

C 7. Vermiculite containing corundum. The specimen selected for examination was very typical and showed a mass of friable, yellowish brown vermiculite with a narrow seam of bright green chlorite dividing it into two nearly equal parts. The corundum is found on only one side of this chlorite seam, but is there in large proportion, some of the crystals being over 2^{cm} in length, the width of the corundum bearing streak being about 15^{cm}. The vermiculite containing the corundum was marked C 7 α; that on the other side of the chlorite, and which showed no corundum, C 7 β. This was followed by

C 8. A combination of vermiculite and actinolite.

C 9. Enstatite mixed with chlorite, forming a tough casing about 10^{cm} thick, inclosing a mass of altered dunyte with the yellow ochers and other characteristic decomposition products.

In giving the results of the examinations of these minerals it may be well to say that the rocks were always examined carefully with a strong lens and in most cases microscopically. The separations were made with Sonstadt's solution whenever practicable; but in the presence of the slimy, yellow, magnesian silicates this was often impossible, and hand picking was resorted to.

ANALYTICAL RESULTS.

C 1. Altered gneiss (?). A friable, sublaminated aggregate of scales of a micaceous mineral, in color from colorless to brownish and reddish yellow, with grains of quartz of similar shades of color and occasional small masses of a whitish, kaolin-like material (**C 2**). This rock has, as stated above, the same strike, dip, and structure as the adjacent unaltered gneiss and apparently passes into it.

C 2. Nodule in **C 1**. Structure finely granular, with larger grains of quartz disseminated through the mass, and a few small, yellowish scales on the fracture surfaces; rather friable; color brownish and yellowish white, with some small brown spots.

C 3. A friable aggregate of micaceous minerals, similar in structure and appearance to **C 1**, but the scales are smaller and more deeply colored in shades of brown and yellow, the grains of quartz are fewer and smaller, and the nodules C 2 are absent.

	C 1.	C 2.	C 3.
Ignition	4.97	2.79	7.96
SiO_2	64.27	75.62	56.65
TiO_2	1.32	None	0.44
P_2O_5	0.05	None	Trace
Al_2O_3	16.75	12.52	21.60
Fe_2O_3	6.08	2.52	6.36
FeO	0.89	0.56	0.70
MnO	0.07	0.42	0.13
CaO	0.25	5.58	0.35
MgO	1.74	0.27	3.61
K_2O	3.09	None	1.98
Na_2O	0.89	None	0.59
	100.37	100.28	100.37

C 4. Soft, friable, fine granular, yellowish white, kaolin-like material in lumps, with dark brown spots and streaks. Contains a very small proportion of fine grains of quartz.

C 5. The lumps of **C 4** are scattered through a seam of a small foliated mineral aggregated to a loosely coherent mass which breaks up when handled. The scales have a pearly luster and are apparently colorless or of a greenish tint, but are stained reddish brown by interlaminated ferric oxide whichcannot be separated from them. When heated the mineral exfoliates slightly, assuming a silvery luster and a purplish red color. Before ignition, decomposable by hot, concentrated hydrochloric acid.

C 6. A compact mass of translucent scales; color, yellow with shades of brown; apparently homogeneous, but altered; disintegrates easily; contains a little chromite (0.15 per cent.).

	C 4.	C 5.	C 6.
Ignition	13.70	12.63	9.46
SiO_2	45.71	37.96	52.59
Al_2O_3	35.49	22.53	5.26
Cr_2O_3	....	....	0.52
Fe_2O_3	1.82	11.12	2.33
FeO	0.60	0.30	0.69
MnO	0.06	0.12	0.12
CaO	0.30	None	0.33
MgO	1.61	15.46	28.53
Alkalies	0.34	Undet.	0.16
	99.63	100.12	99.99

C 7 α and C 7 β. This occurrence has been described above. The two vermiculites show but little difference in physical characteristics, both being fine, scaly, and of a pale brown yellow color. The thinnest scales have a pearly luster and are nearly transparent. C 7 α was carefully hand picked and showed no corundum under a magnifying glass, but the presence of it was shown not only in the course of the analysis, but also in the process of grinding, as the vermiculite when pure is quite soft and free from grit. The corundum is probably interlaminated with the vermiculite, as is often seen in specimens which are more broadly foliated;[1] moreover the corundum crystals, as separated from the gangue, are very much fractured and fall readily to pieces, often forming thin plates. C 7 β appears to be free from corundum. The analyses are given with total amount of water and are also calculated as being free from corundum and dried at 110°, the latter calculation showing that the two vermiculites are practically identical.

The narrow seam of chlorite separating these two was not examined chemically, as it did not differ apparently from the ordinary chlorites of this region. One chlorite (Analysis F, see page 56) has been examined on account of its peculiar appearance, but in most cases it was not deemed necessary:

	C 7 α.		C 7 β.	
	Air dried.	At 110°.	Air dried.	At 110°.
Corundum	8.87	....	None	....
H_2O at 110°	10.33	....	11.42	....
H_2O at red heat	9.47	11.60	10.05	11.34
SiO_2	31.01	38.02	32.97	37.22
Al_2O_3	15.14	18.56	17.88	20.19
Fe_2O_3	5.63	6.90	4.76	5.37
FeO	0.55	0.68	0.57	0.64
MnO	0.12	0.15	Trace	....
CaO	0.35	0.44	None	....
MgO	19.08	23.38	22.36	25.24
Alkalies	0.22	0.27	None	....
	100.77	100.00	100.01	100.00

C 8. A mass of a yellowish brown, small foliated mineral, through the central part of which runs an irregular seam of a fine, granular, grass green mineral intermixed with a small quantity of black magnetic grains and a large proportion of the vermiculite scales, which are, however, much smaller than those of the outer portions. As there were con-

[1]Jenks, quoted by Cooke, Proc. Am. Acad., 1874, loc. cit.; Genth, Am. Phil. Soc., Sept. 19, 1873, section Chlorite.

siderable differences in the specific gravity of these minerals, they were separated by Thoulet's solution and marked **C 8** α, **C 8** β, and **C 8** γ.

C 8 α. Small rounded grains showing some octahedral faces; opaque; luster, submetallic; color, brownish black; streak, blackish brown; magnetic. Analysis corresponds to chromite intermixed with some magnetite, but FeO was not determined for itself, the whole of the Fe_2O_3 being calculated as such.

C 8 β. Finely granular, compact, the larger pieces showing under the magnifying glass a crystalline structure and longitudinal striations; translucent to subtransparent; luster, vitreous; color, grass green; streak, greenish white; sp. gr., 3.062. Analysis corresponds to actinolite.

	C 8 α.	C 8 β.
H_2O at 110°	....	0.04
H_2O at red heat	....	0.52
SiO_2	3.20	${}^{a}_{2}$55.23
TiO_2	0.36	None
P_2O_5	0.12	None
Cr_2O_3	45.94	0.19
Al_2O_3	2.51	${}^{a}_{2}$3.04
Fe_2O_3	....	1.88
FeO	42.90	2.51
(Ni,Co)O	....	Trace
MnO	0.84	0.26
CaO	None	13.36
MgO	3.91	22.31
Alkalies	....	0.58
	99.78	99.92

C 8 γ. Foliated, compact; folia generally small, not over 2^{mm} across; cleavage, basal, eminent; color, yellowish brown, the thinnest scales being almost colorless, with a greenish tint; luster, submetallic, somewhat greasy, the material having a great resemblance to the so-called "bronze powder." Easily decomposed by concentrated hydrochloric acid, the silicic acid separating in pearly scales. When heated gives off much water and exfoliates with considerable force, particles being projected several centimeters from the mass, which doubles its bulk and becomes reddish brown with a somewhat silvery luster. Examined microscopically by Mr. J. S. Diller, who reports "that it is biaxial and negative, but the angle between the optic axes, as seen in a cleavage plate split off parallel to the base, is uniformly small. Upon rotating the section, although the cross is plainly distorted into two hyperbolæ, they do not completely separate from each other." Sp. gr., 2.613 in water at 25.5°.

In the following water determinations the figures in brackets represent determinations by difference, the others being direct determinations.

	Per cent.	Per cent.	Per cent.	Per cent.	Average.
H_2O at 110°	3.87	3.81	3.72	3.72	3.78
H_2O at 130°	0.12				
H_2O at red heat (blast lamp)	(6.83)	7.04	(6.95)	(7.00)	(6.98)
Total H_2O as determined	10.82	(10.85)	10.67	10.72	10.76

Analyses Nos. 1 and 2 are the results obtained on the air dried mineral; No. 3, average of 1 and 2, and No. 4 the average calculated as dried at 110°.

	1.		2.	3.	4.
H_2O at 110°	3.78		(3.78)	3.78	....
H_2O at 130° and red heat	6.98		(6.98)	6.98	7.22
SiO_2	39.89		39.74	39.81	41.17
Al_2O_3	12.88			12.99	13.43
Cr_2O_3	0.54			0.54	0.56
Fe_2O_3	5.29	= 18.82	19.04	5.29	5.47
FeO	0.11			0.11	0.11
MnO	0.05		0.05	0.05	0.05
CaO	0.14		0.13	0.14	0.14
MgO	24.88		24.78	24.83	25.68
K_2O	5.76		(5.76)	5.76	5.96
Na_2O	0.20		(0.20)	0.20	0.21
	100.50		100.46	100.48	100.00

No. 4 gives the atomic ratio:

$$\stackrel{..}{Si} : \stackrel{...}{R} : \stackrel{.}{R} : \stackrel{.}{R} : \stackrel{.}{H}$$
$$2.75 : \underbrace{1.03 : 1.29 : 0.14}_{} : 0.80$$
$$2.75 : 2.46 : 0.80$$
$$7 : 6 : 2$$

As this mineral appears to be a very definite vermiculite, I have, in order to distinguish it from the others, given it the name lucasite, in honor of Dr. H. S. Lucas, of Corundum Hill, North Carolina, and the following table from Professor Cooke's paper[1] will show its relations to the other members of the group at 100°.

	$\ddot{Si}$:	$\dddot{R}$: $\dot{R}$: $\dot{R}$	: H
Hallite	2.42 :	2.41	: 1.47 or 8 : 8 : 5
"Lerni"	2.54 :	2.50	: 1.30 or 2 : 2 : 1
Pelhamite	2.75 :	2.46	: 1.26 or 9 : 8 : 4
Culsageeite	2.50 :	2.66	: 1.23 or 2 : 2 : 1
"Millbury"	2.38 :	2.74	: 1.14 or 2 : 2 : 1
Jefferisite	2.56 :	2.53	: 1.17 or 9 : 9 : 4
Lucasite	2.75 :	2.46	: 0.80 or 7 : 6 : 2

C 9. Grayish white, asbestiform mass made up of fine fibers of a vitreous luster, aggregated to a somewhat woolly mass intermixed with a smaller proportion of bright green chlorite. The rock mass disintegrates easily, breaking down into a soft, woolly aggregate of fine needles, not folia. A hydrous enstatite. Sp. gr., 2.872.

H_2O	4.55
SiO_2	56.58
TiO_2	None
Cr_2O_3	0.24
Al_2O_3	1.74
Fe_2O_3	1.89
FeO	3.67
MnO	0.21
CaO	0.59
MgO	30.34
Alkalies	0.17
	99.98

The dunyte alteration following **C 9** was very much decomposed, being a friable, clay-like mass with needles of white, hydrous enstatite, like **C 9**, and small scales of another mineral which, however, could not be separated in a pure condition by means of Sonstadt's solution, as almost all the scales showed, when examined under the microscope, that they were interpenetrated by the needles. The examination of the decomposed dunyte of the **A** series will, however, show the character of these alteration products.

Of the following analyses, D is from the apparently least altered specimen of dunyte that I was able to find. It is granular, crystalline, the grains of olivine being subtranslucent, with a subvitreous luster and of an oil green color with grayish tints. The rock contains a little chromite.

Some of the specimens of dunyte, particularly the darker varieties, show an indistinct radiated structure, the radiations starting from points which are lighter in color than the rest of the specimen.

[1] Cooke, Proc. Am. Acad., p. 461, 1875.

E is my old analysis of dunyte from the same locality, given in Dr. Genth's first paper on corundum, already cited.

	D.	E.
Chromite	0.56	....
H_2O	2.74	1.72
SiO_2	40.11	41.58
Cr_2O_3	0.18	....
Al_2O_3	0.88	0.14
Fe_2O_3	1.20	....
FeO	6.09	7.49
NiO (tr. Co and Mn)	....	0.34
CaO	....	0.11
MgO	48.58	49.28
	100.34	100.66

A 7 is the casing of the dunyte nodule of the **A** series. It is brownish yellow, granular, and, when dry, easily pulverized; but, some portions appearing harder than the rest, the specimen was crushed without grinding, the coarse powder shaken violently and then sifted through a fine sieve. The softer part was called **A 7** *α*, the harder **A 7** *β*, and it will be seen that the two are practically alike, the harder part containing much more chromite and being not quite so much decomposed.

	A 7 *α*.	A 7 *β*.
Chromite	0.17	2.45
Ignition	2.14	2.01
SiO_2	40.04	40.18
Al_2O_3	3.17	1.35
Fe_2O_3	12.15	9.88
MgO	42.97	43.84
	100.64	99.71

A 8. Altered dunyte, granular, compact, traversed by small seams carrying **A 9.** Luster, dull; color, pale yellowish brown. From interior of nodule.

A 9. Fine fibrous or small foliated, the folia being so arranged transversely in the seams of **A 8** as to present a fibrous appearance. Luster, pearly soft; color, colorless to white. Subtranslucent.

F. Chlorite; broad foliated, folia brittle, being probably somewhat altered. Color, dark bluish green; luster, submetallic. From Corundum Hill.

	A 8.	A 9.	F.
H_2O	1.54	4.32	12.71
SiO_2	40.25	56.39	35.88
Al_2O_3	0.96	2.31	20.90
Fe_2O_3	2.71	0.16	6.55
FeO	5.97	1.96	3.68
CaO	....	0.04	0.14
MgO	47.76	34.57	19.90
K_2O	....	....	0.19
	99.19	99.75	99.95

In comparing these analyses with reference to the mode of occurrence of the corundum and to the question of its probable origin, it must be remembered that we start from an aluminous rock, gneiss, on one side of the seam, and, passing through the series, reach as a final term a magnesian rock, dunyte. In following the series we should expect to find a progressive increase in the amount of magnesia and a gradual decrease in the amount of alumina. It will be observed that such is the case with the magnesia, while, roughly speaking, it is also true of the alumina. The ease with which magnesia, in the processes of rock alteration, may be dissolved and redeposited explains the regularity of its increase, while the high degree of insolubility of silicate of alumina and the presence of varying quantities of kaolin in the specimens **C 1** to **C 6** account for the irregularities in the alumina percentages. The members of the series **C 1** to **C 6**, though crystalline, are in nearly every case much decomposed and do not allow, generally, of proper separations. Enough has been done, however, to show that the entire series falls into three groups: aluminous silicates, alumino-magnesian silicates, and magnesian silicates. The list of constituents is practically the same for all, and it is only by considering the relative predominance of one or the other base that the distinction can be made. The middle term of the chemical series is also the middle term of the field series, and in it the corundum is found. All the gneiss dunyte contacts which I have seen or have information of give practically the same succession. Corundum is, however, only an accessory; frequently it is not found at all, and, when present, often in comparatively small quantities. It may therefore be considered as the result of a certain balance between the aluminous and the magnesian solutions, which have by their union produced the chlorites and the vermiculites.

The question of the origin of the dunyte, in so far as it has any reference to that of the corundum, can now be considered. Three modes of origin are supposable, chemical, sedimentary, and igneous. If a chemical origin be assigned to the dunyte (and gneiss), we could have a sequence of events something like the following: An aluminous silicate solution depositing the constituents of gneiss gradually becomes impregnated with a solution of magnesia either as silicate, or, more probably, a mixture of silicate and carbonate. The researches of Way[1] and those of Deville, Friedel and Sarrasin, and de Schulten[2] have shown that aluminous silicates and alkaline silicates can be made to combine, forming feldspars and other alkaline-aluminous silicates, and Way showed that the alkali could be replaced by lime.

Although much more work is required in this direction, still we are warranted in assuming that, if we can obtain solutions of aluminous silicates and of magnesian silicates and allow them to react upon each other under proper conditions, we shall obtain hydrous-alumino-magnesian silicates, or if iron be present, as is the case with dunyte, silicates belonging to the chlorite and vermiculite groups.

Under this assumption, the rock forming solution would cease depositing the constituents of gneiss, even of the more hornblendic varieties, and, instead, furnish chlorites and allied minerals, until, gradually becoming more and more magnesian, enstatites, talcs, and finally chrysolites would be the products. To account for the formation of corundum during this process we must suppose the presence of carbonate of magnesia along with the silicate, which would permit of the replacement, by magnesia, of a part of the alumina, which would be precipitated either as the hydrate or, under conditions as yet unknown, as corundum.

If instead of a chemical origin for the gneiss and dunyte we consider them as results of either a sedimentary or an igneous action, we shall find the reactions involved in the alterations of these rocks to be of the same character. In either case we should have gneiss in contact with dunyte. As soon as alteration of the gneiss begins, the feldspar kaolinizes and the mica is attacked, yielding solutions of alkaline salts which have the property of dissolving alumina, and this action is increased by the presence of carbonic acid, while even solutions of iron silicates and magnesian silicates have the same effect.[3]

As Roth observes, accurate and sufficient data are lacking for the proper consideration of such questions, but enough is known to be able to say that the alteration of gneiss or granite furnishes a solution of silicate of alumina. On the other hand, the mode of alteration of olivine has been studied,[4] and we know that both magnesia and silica are removed, the former in excess and therefore probably as carbonate,

[1] Way quoted by Hunt, op. cit., § 97.

[2] Hunt, op. cit., §§ 98–99. Fouqué et Lévy, Synthèse des minéraux et des roches, pp. 32, 134, 161–164, Paris, 1882.

[3] Roth, Chem. Geol., Vol. I, pp. 112, 141–160, 305–334, Berlin, 1879.

[4] Roth, Chem. Geol., p. 113.

which, as such, is not an uncommon occurrence among these rocks. Iron would, of course, be dissolved in the same manner as magnesia.

Julien, in his paper already cited, says (page 147):

The corundum itself is in all cases, both in the veins and in the particles found in the gabbro, a secondary or alteration product. All the phenomena of alteration, both in the veins and rock masses, absolutely require and can be simply explained by the introduction of a solution of soda and alumina into the fissures and interstices during the period of alteration and metamorphism. The combination of soda with silicates of alumina and iron, perhaps previously formed, has produced all the minerals of the vein series; while the precipitation of the alumina naturally ensued from the separation of its alkaline solvent. The question then presents itself of the evidence of the introduction of such a solution. This is found in the strata of hornblende gneiss, which everywhere surround the dunyte beds and are abundantly traversed all along the dunyte belt by huge veins of endogenous granite. Into these there has certainly been an introduction, by subterraneous thermal solutions, of soda and alumina, as shown both by the development of a long series of crystallized mineral silicates containing those bases with other elements, and, elsewhere, even by the precipitation of corundum itself (in association with muscovite, margarite, and albite) in a certain class of small veins in the gneiss of limited occurrence but of great interest.

Professor Julien's extended field experience among these rocks gives great weight to his opinion that corundum is a product of rock alteration. It is, indeed, difficult to see how a different opinion can be arrived at, if these rocks are studied in the field. In my own case, my field notes, written before I had an opportunity to see his valuable paper, indicate the same conclusion. Whether the solutions of soda and alumina must be heated in order to effect the production of these minerals is a question to which, at present, no definite answer can be given; but it would seem that the ordinary subaërial decay of these rocks should furnish the necessary solutions. The observations of Becker and the experiments of Barus[1] show that there is considerable doubt as to any production of heat as a result of the kaolinization of feldspar, and if such is the case with feldspar it is not likely that the alteration of any of the other mineral species present in these rocks would be attended by any marked rise in temperature. We must therefore conclude that the gneiss can furnish an alkaline solution of alumina and the dunyte a solution of magnesia without the production of heat and perhaps without its aid. Unless heat be absolutely necessary, either for the production of these solutions or for the formation of the contact minerals, we have no need for the introduction from a deeper source of a heated solution of alumina and soda, as the solutions furnished by the rocks at the contact should be sufficient for the purpose, and, by their meeting at the contact of the formations, give rise to the reactions stated above, namely, the production of chlorites and vermiculites, and, if the necessary conditions of proportion are reached, of alumina or corundum. That these conditions are often lacking is shown by the comparative

[1] G. F. Becker, Geol. of Comstock Lode, Mon. U. S. Geol. Surv., Vol. III, Chaps. VII and IX.

rarity of the occurrences of corundum when the number of such chlorite bearing contacts is considered.

Among the miners chlorite or vermiculite is considered a "corundum sign," and they follow it as long as it holds out. The chlorite veins often extend for some distance into the dunyte, as should be expected when we consider the thoroughly fractured condition of the dunyte, with its consequent spheroidal alteration forms; but, in such cases, the connection with the contact can generally be traced. In the same manner the chlorite seams may extend into the gneiss.

It has already been said that the dunyte of Corundum Hill lies between hornblende gneiss and mica schist. The same can be said of the locality at Unionville, Chester County, Pennsylvania, and, to a certain extent, of that at Chester, Massachusetts.

Mr. W. W. Jefferis has kindly furnished me with much information about the former place, where the serpentine (probably resulting, as stated by Genth,[1] from the alteration of chrysolite rocks) lies between mica schist on the north and hornblende gneiss on the south. The great mass of corundum which was found at this place lay on the north side, in the serpentine, a short distance from the mica schist, and was accompanied by chlorite. "It was between well defined walls of serpentine" (Jefferis). At a point on the south side of the serpentine, at the contact with the hornblende gneiss, is "a digging 15 feet deep, which produced 500 pounds of extra fine, blue corundum, similar to the blue from Macon County, North Carolina. Culsageeite occurs here identical with the North Carolina specimens. Both the corundum and the culsageeite are so much like the Carolina mineral that it is difficult to tell them apart" (Jefferis).

The deposit at Chester, Mass., is a vein of emery situated nearly in the center of the Green Mountain chain.

It is included in the metamorphic series of rocks, here consisting of vast breadths of gneiss and mica slate, with considerable interpolations of talcose slate and serpentine. Strike, N. 20° E.–S. 20° W.; dip from vertical to 75°–80°, sometimes east, sometimes west. The immediate vicinity of the mine presents a succession of lengthened rocky swells; the longer axis of the elevations generally coinciding with the direction of the strata.

The emery vein traverses, in an unbroken line, the crests of two of these adjacent mountains, and is about 4 miles long and about 4 feet wide. It lies at the junction of the gneiss with the mica slate, just within the western edge of the gneiss, having throughout a layer of gneiss 4 to 10 feet in thickness for its eastern wall. Between this layer of gneiss and the mica slate is talcose slate about 20 feet thick at the south end and widening out at the northern end to nearly 200 feet.

[1] Genth, Am. Jour. Sci. (II), XXXIII, p. 202, 1862.

The gneiss is highly hornblendic; where hornblende is rare, epidote is found. Quartz is very deficient and no corundum is found in the gneiss. The talcose slate carries soapstone, chlorite, talcose dolomite, &c., and contains, here and there, corundum. Quartz is very rare. In the vein are found corundum, magnetite, margarite, ripidolite, biotite, andestite, tourmaline, and titaniferous iron.[1]

Whether or not this locality can be placed with those already described is a question to which, not having visited the mine, I cannot give an answer. There are many points of similarity, but the presence of the thin wall of gneiss on the eastern side of the vein brings a difficulty into the consideration of the problem. The presence of magnetite must also be explained; and, as the action of lime is here evident, it may be that this occurrence must be placed with that of the Cullakenee or Buck Creek Mine, Clay County, North Carolina, where lime has also played a part, as shown by the presence of margarite, zoisite, and oligoclase, the last carrying corundum.

The action of lime brings us to the occurrences of corundum in crystallized limestone, of which the emery deposits of Asia Minor and the Greek Islands, studied by J. L. Smith,[2] are the most important. In his memoir he says:

> In every instance I have found the emery associated with the old limestones overlying mica slate, gneiss, &c. It is embedded either in the earth that covers the limestone or in the rock itself, and exists in masses from the size of a pea to that of several tons' weight, generally angular, sometimes rounded, and, when in the latter form, they do not appear to have become so by attrition. * * * The emery has been formed and consolidated in the limestone in which it is found and has not been detached from older rocks, as granite, gneiss, &c., and lodged in the limestone at the time of its formation. My reasons for so thinking are the following:
>
> (1) In no instance could the closest investigation of the older rocks of these localities that are below the limestone furnish the slightest indication of the existence of emery there; and, moreover, the masses of emery in the limestone never had fragments of another rock attached to them. A few thin layers of mica slate were found in the limestone, but they were not in contact with the emery, nor contained any traces of corundum.
>
> (2) The limestone immediately in contact with the emery differs almost invariably in color and composition from the mass of the rock; and at Kulat, where the marble forming the rock is remarkably pure, the part in contact with the emery is of a dark yellow color resembling spathic iron, and contains a large portion of alumina and oxide of iron. The thickness of this interposing coat between the emery and the marble is variable; but, what is certain, it passes gradually into white marble, so that their crystalline structures run into each other, showing that they are one and the same rock. * * * What we see is just what should be expected in ferruginous and aluminous minerals forming and separating themselves from a limestone not yet consolidated.

Other reasons are given to prove this point, and he gives a most instructive example of a nodule of emery surrounded by two concentric layers, the inner of chloritoid, a hydrous silicate of alumina and iron,

[1] J. L. Smith, Am. Jour. Sci. (II), XLII, pp. 83–93, 1866.

[2] Am. Jour. Sci. (II), X, pp. 354–370, 1850; XI, pp. 53–66, 1851.

the outer of margarite, a hydrous silicate of alumina and lime. Finally he says:

At some future time * * * it will doubtless be found that emery forms the geognostic mark of extensive calcareous formations in that part of the world, just as the flints do in the chalk of Europe.

CONCLUSION.

From the foregoing examples it would seem that we have three types of corundum occurrences:

(1) In chlorites and allied minerals, the result of contact alterations between aluminous-alkaline silicate rocks and magnesian silicate rocks.

(2) In soda-lime feldspars, mainly depending upon the same reactions as No. 1, but complicated by the action of lime.

(3) In crystallized limestone, represented by the emery occurrences and that at Vernon, Sussex County, N. J., described by W. P. Blake.[1] As to the character of the reactions producing this last class of occurrences, I am not at present able to say anything, and it will require a careful study of the relative influence of magnesia and lime, in this connection, before any hypothesis can be stated.[2]

In considering the second type the facts that the feldspar is always a soda-lime feldspar, that it is found in connection with occurrences of the first type, and that margarite and other lime minerals are found in association point to a modification of type No. 1 through the action of lime. If the "hornblende gneiss" of the Buck Creek or Cullakenee Mine proves to be diorite, as has been stated, then we may be able to form a simpler idea of the course of the reactions.

The mode of origin of the dunyte is readily seen to be foreign to that of the corundum, since the chemical reactions involved in the production of the latter are practically the same under each theory. If a chemical origin be assigned to the dunyte, then the corundum and chlorite would be formed posterior to the gneiss and anterior to the dunyte, or even vice versa. If either the mechanical sedimentary or the igneous theory be assumed, then the corundum is posterior to both gneiss and dunyte and contemporary with the chlorite (and vermiculite), the two being equally alteration products. On the whole, it would seem that an igneous origin for the dunyte offers the simplest explanations.

That the chlorite and the corundum are contemporaneous is made evident by the intimate manner in which the two have crystallized together. In general the plates of chlorite would seem to have attained considerable size before the corundum began to deposit and fill up the interstices, so that we have compact masses ranging all the way from almost pure corundum to almost pure chlorite. The "block corundum" of Laurel Creek is an example of the first class, while the "sand vein

[1] Am. Jour. Sci. (II), XIII, p. 116, 1852; C. U. Shepard, Am. Jour. Sci. (III), IV, p. 179.

[2] J. L. Smith, Am. Jour. Sci. (III), VI, p. 182.

chlorite" of the same place shows the latter form. While perfectly formed crystals of pure corundum are not uncommon, we frequently find crystals with regular faces, but apparently formed in a solution having large numbers of small plates of chlorite or vermiculite floating in it, so that the corundum crystals carry many of the folia inclosed in them. If such a crystal, carrying vermiculite, is boiled in acid, the vermiculite is decomposed and more or less of the crystal disintegrates into corundum sand. Such crystals are found at Corundum Hill and specimens exist in the collection of the National Museum.

Whether or not the vermiculites are to be considered as resulting from the alteration of chlorites is a disputed point. Specimens are frequently found which show an apparent change from chlorite into vermiculite, the dark green folia of the one passing into the yellow brown of the other,[1] but in most cases it is difficult to resist the conclusion that the chlorite now found with the vermiculite is not the residue of a process which has converted the rest into vermiculite. Such specimens from Corundum Hill show the chlorite apparently perfectly fresh and the form of the mineral entirely distinct from that of the associated vermiculite, being usually much more broadly foliated. Moreover, we find seams containing but little chlorite, the corundum being surrounded by vermiculite, while, but a short distance away and under apparently like conditions of exposure and weathering, veins are found filled with chlorite almost free from vermiculite. In this connection the observations of Cooke[2] are very interesting, and from what we know at present the derivation of one from the other is very doubtful. As to the relation of the chlorites (including vermiculites) to corundum, it is possible that this mineral may, in the process of alteration, occasionally furnish them; still, so far as field experience teaches, these minerals are the original gangue of the corundum and are not derived from it. The valuable researches of Dr. Genth have shown that this mineral does alter, and, in so doing, produces many different mineral species; but whether any given mineral occurring with corundum is a result of the alteration of the latter must be determined for each case by the examination not only of the specimen but of its field surroundings also. Even when we have before us an apparently decided pseudomorph of some mineral after corundum it may prove to be only a case of envelopment, and this is particularly likely to be the case where the mineral in question is found free from corundum in the same vein or even the same locality. Both damourite and margarite are found enveloping corundum, the outlines of the mass closely imitating the form of the inclosed crystal, so as to be easily mistaken for a true pseudomorph, and yet both of these minerals occur with corundum in such a manner that it is hardly possible to conceive that they are derived from it. The same may be

[1] Genth, op. cit., 1873, section "Jefferisite."

[2] Cooke, Proc. Am. Acad., Vol. IX, pp. 49–50, 1874.

said of the lime-soda feldspars, which, in general, present all the appearance of a gangue and not of an alteration product.

In concluding this paper it may be said that the information on this subject which has been gathered by different observers, while in the aggregate of considerable extent, is so far neither sufficient nor of a character to enable any one to speak with any great degree of confidence as to the mode of origin of this interesting mineral. Much more work, both in the field and in the laboratory is necessary; and, as a thorough investigation in this direction cannot fail to elucidate many points of great value to chemical geology, it is to be hoped that such work will be done. The value of corundum from the practical standpoint, the ease with which it can be recognized when occurring with other minerals, the great scientific importance of alumina, not only in its pure and crystallized condition, but also as a principal constituent of the earth crust, and therefore playing a part in almost all geognostic reactions, its varied and sometimes inexplicable chemical behavior, all tend to promise a rich return to the well equipped investigator.

A METHOD FOR THE SEPARATION AND ESTIMATION OF BORIC ACID, WITH AN ACCOUNT OF A CONVENIENT FORM OF APPARATUS FOR QUANTITATIVE DISTILLATIONS.

By F. A. Gooch.

In all successful methods for the estimation of boric acid, its comparative isolation is a necessary preliminary. Fortunately, the removal of nearly everything which interferes seriously with the proper execution of methods is not particularly arduous, but, of ordinarily occurring substances, two, silica and alumina—both very commonly associated with boric acid—are especially annoying in this regard. In the separation of alumina the trouble lies in the tendency of the precipitated hydrate to carry and retain boric acid,[1] so that the two cannot be parted by means of ammonia or ammonia salts; with silica, the difficulty is in removing it completely. The volatility of boric acid stands, of course, absolutely in the way of treating with acid and evaporating to dryness, and every chemist knows the vainness of attempting to precipitate silica by means of ammonia, ammonia salts, or zinc oxide in ammonia. In Stromeyer's method[2] the presence of silica is peculiarly harmful, since in passing to the condition of potassium fluosilicate this substance nearly quadruples its weight, and to free the potassium fluoborate from contaminating fluosilicate requires, according to Fresenius,[3] at least six treatments by solution in boiling water, the addition of ammonia, and evaporation to dryness. Wöhler[4] recommends evaporating the hydrochloric acid solution to dryness in a flask fitted to a condenser, collecting the distillate, reuniting the latter with the residue, and filtering from silica; and the operation is successful so far as the complete removal of silica is concerned, but the alumina, if present, is still in condition to give annoyance, and the other bases are yet to be separated.

Advantage has long been taken of the volatility of free boric acid with hydrofluoric acid or with alcohol to secure its removal from fixed substances, but so far as I know no attempt has been made heretofore to secure its complete volatilization and estimation in the distillate. The experiments which I proceed to describe are the result of an effort to accomplish this end.

[1] Wöhler, Ann. Chem. und Pharm., CXLI, p. 268.

[2] Ann. Chem. und Pharm., C, p. 82.

[3] Quant. Chem. Anal., p. 424.

[4] Handbook of Mineral Analysis, under Datholite.

Aside from the difficulties in manipulation and in the construction of apparatus which the use of hydrofluoric acid would involve, this reagent is otherwise plainly inapplicable to the purpose in view, and of other agents with which boric acid is known to volatilize freely methyl alcohol seems to present the most desirable qualities. Methyl alcohol, ethyl alcohol, and water are effective in the order in which they are named. Thus to volatilize 1 grm. of boric acid—the equivalent, speaking roughly, of about 0.5 grm. of boric anhydride—two treatments with 10 cm.^{3} of methyl alcohol and evaporation to dryness in each case were adequate; for the volatilization of 0.2 grm. of boric acid were required two treatments of 10 cm.^{3} each of ethyl alcohol, succeeding an evaporation with 50 cm.^{3} of the same alcohol; and the residue of five evaporations of water over 0.4 grm. of boric acid, taking in each case 50 cm.^{3} of water, followed by ignition, weighed 0.08 grm., or one-fifth of the original weight. In the presence of water, methyl alcohol is not equally effective; amyl alcohol and sulphuric acid restrain its action similarly, doubtless by dilution simply, and hydrochloric acid seems to possess no advantage over water alone in developing the volatility of boric acid. As an example an experiment may serve in which a solution of 0.4 grm. of boric acid in 50 cm.^{3} of water, after being heated three times successively with 25 cm.^{3} of methyl alcohol until the boiling point rose in every case nearly to that of water, and then evaporated to dryness, left a large residue which disappeared with a single charge of 25 cm.^{3} of methyl alcohol applied by itself.

From the residue of the evaporation of borax with hydrochloric, nitric, or acetic acid, methyl alcohol, as would naturally be predicted, volatilizes the boric acid freely, though the presence of foreign material acts to a certain degree protectively and tends to diminish the rapidity with which the alcohol would otherwise effect extraction and volatilization. In case, however, that acetic acid is used to break up the borate, the tendency of sodic acetate to lose acid and become alkaline simply by exposure to evaporation in its aqueous solution makes it necessary to insure the acidity of the residue of evaporation by adding a drop or two of acetic acid before repeating the treatment with methyl alcohol.

On the whole, methyl alcohol shows itself to be an excellent agent by which to secure the volatilization of boric acid.

To retain free boric acid, magnesium oxide naturally suggests itself. According to Marignac[1] it is effective, and, if in the course of analysis it may have been partly converted to the chloride, it is easily regenerated by the action of heat and moisture. Marignac, it will be remembered, makes use of magnesia mixture—the chlorides of ammonium and magnesium with free ammonia—to fix the boric acid, evaporating the solution to dryness, igniting, extracting with boiling water, filtering, and weighing the residue, while the filtrate is again treated as before to re-

[1] Zeitschr. anal. Chem., I, p. 406.

cover traces of the borate which has yielded to the solvent action of the water. During the drying and ignition the magnesium chloride yields hydrochloric acid, and it would seem scarcely possible that the magnesium borate should fail to show some loss of boric acid when both hydrochloric acid and moisture exert their action. Further, the presence of ammonia during evaporation does not prevent the volatilization of boric acid,[1] and Marignac regards the addition of it from time to time as of doubtful use. So it appears natural to look for some loss under such conditions, and Marignac fully recognizes the fact that the apparent accuracy of his method is due to the balancing of errors, the inclusion of foreign matter by the magnesium borate and the deficiency of the magnesia when precipitated as ammonio-magnesium phosphate together compensating for the loss of boric acid by volatilization. To bring the matter to the test, the following experiments were made. In them and in all succeeding experiments the boric acid was weighed in solution, the standard of this having been fixed by dissolving in a known weight of water a known weight of fused boric anhydride prepared in a state of purity by frequent recrystallization. The magnesium oxide employed was made from the pure chloride by precipitating by ammonium carbonate and igniting, and was free from lime and alkalies and so far as could be determined was otherwise pure. The whole operation of each experiment was conducted in one vessel, so as to avoid transfers. In all cases a weighed platinum crucible of 100 cm.^{3} capacity received a weighed portion of magnesia, and after ignition and subsequent weighing the weighed solution of boric acid was introduced. In experiments (1) to (4) the magnesia was thoroughly stirred in the solution of boric acid, the evaporation carried at once to dryness, and the crucible and residue ignited and weighed; in experiments (5) to (8), the magnesia was dissolved, after the addition of the boric acid, in hydrochloric acid sufficient in amount to prevent the precipitation of magnesium hydrate on the subsequent addition of ammonia, ammonia introduced in considerable excess in (7) and (8), in distinct excess in (5) and (6), the whole evaporated and ignited, the residue moistened and again ignited, and this last treatment repeated until the residue ceased to yield vapor of hydrochloric acid when heated.

	B_2O_3 taken.	MgO taken.	$MgO+B_2O_3$ found.	B_2O_3 found.	Error.
	grm.	grm.	grm.	grm.	grm.
(1)	0.1734	0.5005	0.6607	0.1602	0.0132 –
(2)	0.1804	0.4973	0.6660	0.1687	0.0117 –
(3)	0.1793	0.4949	0.6640	0.1691	0.0102 –
(4)	0.1794	0.4941	0.6627	0.1686	0.0108 –
(5)	0.1807	0.4984	0.6542	0.1558	0.0249 –
(6)	0.1789	0.4974	0.6687	0.1560	0.0229 –
(7)	0.1806	0.4944	0.6684	0.1740	0.0066 –
(8)	0.1789	0.4959	0.6672	0.1713	0.0076 –

[1] Rose, Pogg. Ann., LXXX, p. 262.

From these results it appears plain that under the conditions of the experiments neither magnesia alone nor the magnesia mixture is efficient in fixing boric acid; but in experiments (7) and (8), in which ammonia was employed in large excess, the loss of boric acid is least; so that it would seem to be the case that though ammonia is not a perfect preventive of volatilization it does exert a restraining action on the boric acid. That the magnesia mixture should be incapable of retaining entirely the boric acid present is, as has been pointed out, not surprising; but that the loss should be so great is rather startling, and more than suggests that the errors of Marignac's process are seriously excessive. The failure of magnesium oxide to hold back boric acid under the conditions of the experiment must be due to a cause other than that which determines the loss during the evaporation and ignition of the magnesia mixture, and for this it is natural to turn to the insolubility of the oxide, a quality likely to oppose some difficulty in the way of establishing complete contact between the boric acid and the magnesia during a short exposure. Direct tests of this point showed distinctly that mixtures of boric acid in water and magnesia, when submitted at once to distillation, yielded boric acid to the distillate; but that, if the mixtures were permitted to stand some hours before distilling, the oxide passed to the semigelatinous condition of the hydrate and retained the boric acid so firmly that turmeric failed to show the presence of the latter in the distillate. It is plain, therefore, that with sufficient preliminary exposure magnesia might be relied upon to retain boric acid; but inasmuch as long and perhaps somewhat indefinite periods of waiting are objectionable in any analytical process, it was thought best to try the effect of substituting lime for magnesia. Experiments (9) to (12), conducted like the previous ones, excepting only the use of carefully prepared and ignited calcium oxide instead of magnesium oxide, were made with this end in view.

	B_2O_3 taken.	CaO taken.	$CaO+B_2O_3$ found.	B_2O_3 found.	Error.
	grm.	grm.	grm.	grm.	grm.
(9)	0.1810	0.9737	1.1560	0.1823	0.0013+
(10)	0.1819	0.9750	1.1583	0.1833	0.0014+
(11)	0.1808	0.9922	1.1810	0.1818	0.0010+
(12)	0.1833	0.9715	1.1560	0.1845	0.0012+

These figures indicate sufficiently that there is no loss of boric acid by volatilization when its aqueous solution is evaporated in contact with calcium hydrate; but, inasmuch as the comparative solubility of the latter is the quality which makes it effective where magnesia is not, it seemed desirable to test the action of calcium hydrate in alcoholic solutions, in which it is very insoluble. The experiment showed that when the solution of boric acid in methyl or ethyl alcohol is put upon lime and distilled at once loss is apt to take place, and sometimes to a very considerable amount, but that a short period of digestion, with occasional stirring—from five to fifteen minutes—is sufficient to obviate danger of volatilization of boric acid.

It appears, therefore, that, free boric acid being easily volatilized by means of methyl alcohol and fixed completely by calcic hydrate, the separation of the acid from almost everything with which it occurs ordinarily and its estimation subsequently depend only upon the practicability of distilling it from its compounds in such company that it may be retained by lime and its amount determined by the increase in the weight of the latter. Unlike magnesium chloride, calcium chloride does not yield its chlorine readily under the action of heat and moisture naturally retained; so that hydrochloric acid must not be present with boric acid which is to be estimated in the manner described. Calcium nitrate and calcium acetate both yield the oxide without difficulty upon ignition, and nitric and acetic acids are suitable agents, therefore, for the liberation of boric acid previous to distillation.

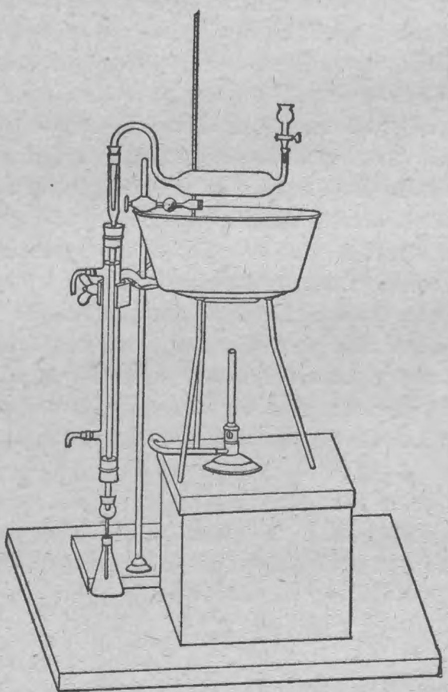


FIG. 3. Apparatus for determination of boric acid.

The actual distillation presented at first some difficulty, for the repeated, thorough, and rapid evaporation of a liquid charged with soluble or insoluble solid matter is apt to involve some mechanical transfer to the distillate of material which should remain in the residue; but the device of the following description solves the problem successfully.

The apparatus which is shown in the accompanying cut consists essentially of a retort, a condenser, and a bath for heating. For the last I have used a paraffine bath, as being, on the whole, the most convenient. The condenser is set vertically, to facilitate changing the level of the retort within the bath and to secure at the same time continual and thorough washing of the tube by its own condensations. The retort, somewhat like the well known drying tube of Liebig in general shape, is easily made of a pipette by bending the tube at one end to a right angle, at the other to a goose neck, as shown. To the former end is fitted, by a rubber stopper or section of tubing, a glass funnel tube provided with a stop cock; the end of the goose neck passes tightly through a rubber stopper in the upper end of the condensing tube. This is essentially the apparatus, but it is convenient to attach, to receive the distillate, a small Erlenmeyer flask, which moves with the condenser and is joined to it, in the manner indicated in the figure, by means of a thistle tube and a rubber stopper grooved to permit the free passage of air. In carrying out a distillation, the liquid to be distilled is introduced into the retort either by the funnel tube or previous to its insertion, the glass cock is closed, the water started through the condenser, and the retort lowered into the hot paraffine, care being taken to begin the operation with the retort not more than half full and so inclined that only the rear dips below the surface of the bath. If the precaution to heat the retort at the start in this manner be overlooked, it may sometimes happen that the sudden and violent expulsion of air through the liquid will carry portions of it bodily into the goose neck, and even into the condenser. With this point considered, the remainder of the operation presents no difficulty and requires little care.

The size of the retort may be suited, of course, to the particular case in hand, but for most purposes a 200 $cm.^3$ pipette makes a retort of convenient dimensions, neither too large for the distillation of small charges nor too small to permit the treatment of 100 $cm.^3$ of liquid comfortably. The tube of the goose neck should be wide enough to prevent the formation of bubbles in it; 0.7 cm. is a good measure for the interior diameter. It is of advantage to heat the bath to a point considerably above the temperature at which the liquid which is to be distilled boils — something between 130° C. and 140° C. does very well for water and is not too high for methyl alcohol — and under such circumstances, and when the retort is entirely submerged, it often happens that evaporation takes place with extreme rapidity from the surface of the liquid in perfect quiet without actual boiling.

With such an apparatus the following experiments were made. The boric acid was weighed, as before, in solution, and, to bring the condition of the experiment to that of an actual analysis, 1 grm. of pure sodium hydrate was added in solution, nitric acid or acetic acid to acidity and a little more, and the whole was introduced into the retort and distilled to dryness.

In those experiments in which nitric acid was employed, the methyl alcohol was introduced upon the residue thus dried in six successive portions of 10 cm.³ each and distilled to dryness; but in order to break up the residue of sodium nitrate, which by its insolubility might affect to some extent the protection of the boric acid from the action of the alcohol, 2 cm.³ of water were introduced and evaporated between the second and third and again between the fourth and fifth distillations.

When acetic acid was made use of to free the boric acid, the six distillations with methyl alcohol were made as before; but, sodium acetate being soluble in methyl alcohol, the intermediate treatments with water were unnecessary. With the fourth portion of methyl alcohol a few drops of acetic acid were added to preserve the acidity of the residue, which, as has been pointed out, tends to become alkaline under the treatment.

The residues of both processes of treatment were found to be free from boric acid by the exceedingly delicate test with turmeric, care being taken in the series of experiments in which nitric acid was used to oxidize nitrites by means of bromine (expelling the latter before making the test), and in the acetic acid series to acidify with hydrochloric acid sufficiently to counteract the tendency of the acetate by itself to brown the turmeric on evaporation.

The lime to retain the boric acid in the distillate was ignited in the crucible in which the evaporation of the distillate was to be made subsequently, and then transferred to the receiving flask attached to the condenser, so that the boric acid might be fixed during the distillation. To prevent the caking of the lime by the action of the alcohol, it was slaked with a little water before the distillation was begun.

In experiments (13) to (16) nitric acid was employed and in (17) to (20) acetic acid was used, with the precaution noted, to liberate the boric acid.

	B_2O_3 taken.	CaO taken.	B_2O_3+CaO found.	B_2O_3 found.	Error.
	grm.	grm.	grm.	grm.	grm.
(13)	0.1738	0.9647	1.1392	0.1745	0.0007+
(14)	0.1806	0.9639	1.1456	0.1817	0.0011+
(15)	0.1779	0.9665	1.1450	0.1785	0.0006+
(16)	0.1824	0.9739	1.1587	0.1848	0.0024+
(17)	0.1806	1.4559	1.6371	0.1812	0.0006+
(18)	0.1812	0.9720	1.1543	0.1823	0.0011+
(19)	0.1788	0.9986	1.1781	0.1795	0.0007+
(20)	0.1813	0.9527	1.1358	0.1831	0.0018+

In experiments (13) to (16) the mean error amounts to 0.0012+ grm.; in experiments (17) to (20) the mean error is a little more than 0.0010+ grm. Throughout the entire series of experiments the tendency to yield figures slightly larger than the truth is manifest, but the error is quite within legitimate limits. The greatest care was taken to secure similarity of conditions under which the crucible and the lime were weighed before and after the evaporation and absorption of boric acid, and the weight after ignition was taken in every case after cooling over sulphuric acid during a definite period of ten minutes, in order to eliminate as far as possible the effect of atmospheric condensation upon the large surface of platinum. Ignitions were always finished over the blast lamp, and constancy of weights was secured.

The results indicate that both modes of treatment are on the whole equally satisfactory.

In the presence of chlorides, it is of course impossible to employ nitric acid to free the boric acid. Oxalic, citric, and tartaric acids also liberate hydrochloric acid to a considerable extent from alkaline chlorides. It was found, however, that when acetic acid was distilled over sodium and potassium chlorides only traces of hydrochloric acid passed into the distillate, and experiments (21) to (23) were made to determine whether these amounts are sufficient to vitiate the separation of boric acid from alkaline chlorides by distillation in presence of free acetic acid. The details of treatment were identical with those of experiments (17) to (20), excepting only the addition of 0.5 grm. of sodium chloride to each portion before distillation.

	B_2O_3 taken.	CaO taken.	B_2O_3+CaO found.	B_2O_3 found.	Error.
	grm.	grm.	grm.	grm.	grm.
(21)	0.1834	0.9842	1.1675	0.1833	0.0001–
(22)	0.1831	0.9755	1.1593	0.1838	0.0007+
(23)	0.1761	0.9740	1.1523	0.1783	0.0022+

The mean error of these results is about 0.0009+ grm., and it is plain that the presence of sodium chloride does not materially change the conditions of the experiment. There seems, therefore, to be no reason why boric acid may not be separated by distillation from alkaline chlorides in presence of free acetic acid; but it was found that the presence of any considerable amount of potassium acetate is disadvantageous. Sodium acetate to a reasonable amount does not interfere with the favorable progress of the separation; but potassium acetate appears to require a much higher temperature for the expulsion of its water, and longer distillation.

When, therefore, chlorides are present in the salts from which boric acid is to be removed by distillation, the choice is open between two methods. The distillation may be made directly with an excess of acetic acid; or the hydrochloric acid may be first removed by means of silver nitrate and the distillation of the filtrate proceeded with at once or after precipitation of the excess of silver salt by means of sodium hydrate or carbonate, care being taken to acidify again sufficiently with nitric acid after the removal of the silver. Of these two modes of proceeding, I incline to the treatment with nitric acid and the removal of the chlorine by precipitation; and this method has been used with success by others as well as myself for some months in the analysis of waters carrying boric acid and natural borates.

The process in either modification is fairly accurate and easily executed and admits of very wide application. Insoluble compounds in which the boric acid is to be determined may be dissolved in nitric acid at once, or, if necessary, first fused with sodium carbonate; and, fortunately, nearly everything which is volatile in the subsequent treatment and capable of forming with lime compounds not easily decomposable by heat may be removed by known processes. The combination of fluorine, silica, and boric acid is perhaps most difficult to treat; but the precipitation and removal of the first as calcium fluoride from the aqueous solution of a fusion in alkaline carbonate may, it is believed, be effected with care, and the mode of procedure from that point is simple.

The number of distillations necessary depends, of course, upon the amount of boric acid treated. To remove 0.2 grm. of boric anhydride completely to the distillate, six charges of methyl alcohol, of 10 $cm.^3$ each, proved, as we have seen, to be ample.

The apparatus by the aid of which the distillation processes which have been described were carried out has found useful application in a number of other processes. In the determination of free and albuminoid ammonia in waters which can be boiled quietly with difficulty, in the methods of estimating hydrofluoric acid which involve the expulsion of silicon fluoride from a mixture of the fluoride with sulphuric acid and silica, in the separation of iodine from bromides and chlorides by distilling with ferric sulphate and sulphuric acid and of bromine from chlorides by means of permanganic acid, it has proved of value, and it will doubtless be found convenient in many analytical processes in which quantitative separations by the distillation of liquids liable to spatter or boil explosively are involved.

A METHOD FOR THE SEPARATION OF SODIUM AND POTASSIUM FROM LITHIUM BY THE ACTION OF AMYL ALCOHOL ON THE CHLORIDES, WITH SOME REFERENCE TO A SIMILAR SEPARATION OF THE SAME FROM MAGNESIUM AND CALCIUM.

BY F. A. GOOCH.

For the quantitative separation of lithium from sodium and potassium Mayer's method,[1] which is based upon the precipitation of lithium as the tribasic phosphate, and Rammelsberg's[2] mode of parting the chlorides by means of a mixture of anhydrous alcohol and ether in equal parts have been available.

The method of Mayer grew out of the older process of Berzelius,[3] which consisted essentially in treating the solution of the alkaline salts with phosphoric acid and sodium carbonate in excess, evaporating to dryness, and extracting with cold water. The result of a single analysis of the product thus obtained was the testimony upon which Berzelius rested the belief and statement that the salt was a double phosphate of lithium and sodium, which left upon ignition sodium and lithium pyrophosphates in equal molecules; and on this Berzelius based his process for the estimation of lithium. Rammelsberg,[4] however, showed later that it was a tribasic phosphate which was actually obtained, and from his experiments arrived at the conclusion that the proportions of soda and lithia were variable within wide limits, the amounts of the former varying in the special cases investigated from 7.84 per cent. to 28.38 per cent.; and the same thing in substance was reiterated subsequently[5] in an account of a repetition of the work suggested by the criticism of Mayer. Mayer,[6] however, was unable to prepare under any conditions the double phosphate of Rammelsberg, and obtained invariably, when the preparation had been washed with sufficient care, trilithium phosphate free from sodium; but the point was made that the phosphate is apt to be contaminated with lithium carbonate when sodium carbonate is employed to bring about alkalinity.

[1] Ann. Chem. u. Pharm., XCVIII, p. 193.
[2] Pogg. Ann., LXVI, 79.
[3] Id., IV, 245.
[4] Loc. cit.
[5] Pogg. Ann., CII, 443.
[6] Loc. cit.

Mayer therefore modifies the method of Berzelius by substituting sodium hydrate for the carbonate, and, proceeding, evaporates to dryness, treats the dry mass with as much water as is needed to dissolve the soluble salts with the aid of heat, adds a drop or two of sodium hydrate if necessary to restore alkalinity, and then ammonia in volume equal to that of the water already added, sets aside at a gentle heat, filters only after twelve hours, and washes with a mixture of ammonia and water in equal parts. From the filtrate and first washings a small amount of the lithium phosphate is to be recovered by evaporation and the repetition of the former treatment. According to Mayer the precipitation of the phosphate may be effected with equal completeness by boiling the solution, prepared as before, instead of evaporating it; but the objection to this mode of proceeding is the tendency of the liquid carrying the precipitate to bump explosively. Careful washing, somewhat prolonged, is essential to secure the complete removal of salts of sodium and potassium, and it is remarked that the purity of the precipitate is shown by its failure to cake when strongly ignited.

This is the mode of proceeding by which Mayer separates lithium from sodium and potassium, isolating it as presumably pure trilithium phosphate and weighing it as the anhydrous salt. In dealing with mixtures of the chlorides in which the proportion of the lithium salt is relatively small, the removal of the greater part of sodium and potassium chlorides by a preliminary treatment with absolute alcohol is recommended. The following table comprises the results of Mayer's test analyses of lithium carbonate in the first seven, of lithium sulphate in the last two, recalculated with the use of the number 7 — the figure now generally accepted — as the atomic weight of lithium.

Li_3PO_4 equivalent to salt taken.	Li_3PO_4 found.	Error.
grm.	grm.	grm.
1.3586	1.3719	0.0133+
1.5172	1.5088	0.0084−
0.7519	0.7580	0.0061+
0.9561	0.9510	0.0051−
1.2651	1.2646	0.0005−
1.2197	1.2230	0.0033+
0.8991	0.9018	0.0027+
1.1325	1.1236	0.0089−
0.9715	0.9665	0.0050−

Fresenius[1] found on examining the method that several repetitions of the treatment by evaporation and extraction were required to complete the recovery of all lithium phosphate, and advised that the operation be continued until residual lithium phosphate fails to appear. The results of Fresenius's experiments with lithium carbonate, recalculated

[1] Zeitschr. anal. Chem., I, p. 42.

with the use of the number 7 as the atomic weight of lithium, are given in the table appended.

Li_3PO_4 equivalent to salt taken.		Li_3PO_4 found. Dried at 100° C.	Ignited.	Error.
grm.		grm.	grm.	grm.
0.7443	after two treatments	0.7243	......	0.0200 −
	" three "	0.7385	......	0.0058 −
	" four "	0.7433	......	0.0010 −
0.9820		0.9861	......	0.0041 +
		......	0.9826	0.0006 +
1.6341		1.6342	......	0.0001 +
		......	1.6305	0.0036 −

Thus it will be seen that in the nine experiments of Mayer the error ranges from 0.0133+ grm. to 0.0089 — grm., and that of the determinations of Fresenius from 0.0001+grm. to 0.0041+grm. for the dried precipitate and from 0.0006+ grm. to 0.0036 — grm. for the ignited precipitate.

If the tendency of lithium carbonate to fall in company with the phosphate were not to assert itself during the evaporations of solutions of salts of lithium in presence of sodium hydrate and in contact with ordinary atmospheric air, it would surely be strange, and this point may be fairly set down as one of the weak ones of the method; but the gravest source of error, and that indicated most unmistakably throughout the whole history of the process — which has been recounted at some length for the purpose of emphasizing this very matter — is the impossibility of preparing the lithium phosphate in anything like a condition of freedom from other alkaline phosphates without a careful and prolonged washing, which is sure to result in loss of the lithium salt by solution. When it is remembered that according to Mayer's determinations trilithium phosphate requires for solution only 2,539 parts of water or 3,920 parts of a mixture of ammonia and water in equal portions, it is plain that the success of the method depends upon the ability of the analyst to wash to a condition of purity, and without loss of that which it is the purpose of the process to save, a precipitate peculiarly prone to retain foreign matter and soluble in the washing mixture in the proportion of 10 milligrams to every 40 $cm.^3$ of the latter. Of course washings will never be entirely saturated, nor will the precipitate be as soluble at the beginning of the operation as at the end, when the precipitant no longer exerts an action which tends to lessen solubility; but in view of the difficulties which present themselves, it is sufficiently obvious that exact results obtained by Mayer's process owe their apparent accuracy to a fortuitous balance of errors. The difference of 0.0222 grm. between the extremes of Mayer's experimental results should not be surprising; and, at the best, the process is tedious and not entirely trustworthy, facts of which its author was not unmindful.

In Rammelsberg's method of separating lithium chloride from the chlorides of sodium and potassium the sources of error are, in brief, the solubility of sodium chloride and potassium chloride in the ether-alcohol mixture, the influence which the presence of small amounts of water exerts upon the solubility of these same salts, the difficulty of bringing the chlorides to the anhydrous condition without decomposing the lithium chloride to a greater or less extent, and the mechanical difficulties of transferring the fused or crusted chlorides to a suitable receptacle for digestion and agitation in the solvent, and of extracting perfectly the soluble constituents of closely compacted matter. Of the last two items nothing need be said in explanation beyond simply noting them. The third is particularily important, inasmuch as the tendency of lithium chloride, first noted I believe by Mayer, to exchange chlorine for oxygen when ignited in presence of water, results in the formation of lithium hydrate or, in contact with products of combustion, lithium carbonate, both of which are insoluble in the mixture of ether and alcohol and remain with the sodium and potassium chlorides. As to the effect of water in the mixture, an experiment of Mayer, in which it was found that 100 $cm.^3$ of a mixture of alcohol of 96 per cent. and ether of 98 per cent. dissolved 0.1100 grm. of sodium chloride, is instructive. In regard to the solubility of the chlorides of sodium and potassium in the mixture of anhydrous ether and alcohol, Rammelsberg's statement that from 0.9770 grm. of pure, strongly heated sodium chloride with an undetermined amount of lithium chloride the mixture extracted 0.0130 grm. is unfortunately meaningless in the absence of information concerning the amount of solvent employed. J. Lawrence Smith[1] found, in making an examination of this matter, that 10 $cm.^3$ of the anhydrous ether-alcohol mixture extracted from 0.5 grm. of sodium chloride 0.0005 grm. and from 0.5 grm. of potassium chloride 0.0003 grm. Smith's mode of applying the method is better than the original; for, by taking care not to heat the mixed salts above 100° C., the danger of decomposing the lithium chloride is diminished, and by treating the dried salts with the ether-alcohol mixture in the capsule in which it is heated and weighed (protecting it by a small inverted bell glass) the disadvantage of the transfer is avoided, but the danger is incurred that the mixed salts may not be thoroughly dried by heat so gentle. With this modification Smith obtained results which are rearranged in the following statement, and which do not throw a very favorable light upon the method:[2]

[1] Am. Jour. Sci. (2), XVI, p. 56.

[2] Dr. Smith's language in the description of these experiments is somewhat ambiguous, but it is believed that these figures represent the meaning intended. After the presentation of the data of the first experiment given here with the correction of an obvious typographical error, it is said of the second and third experiments that "a similar mixture containing 18.10 per cent. of chloride of lithium furnished a residue of 17.65 per cent." and "a similar mixture containing 67.20 per cent. of chloride

NaCl taken. grm.	KCl taken. grm.	LiCl taken. grm.	Weight dissolved. grm.	Error. grm.
0.2000	0.2000	0.0080	0.0101	0.0021+
0.2000	0.2000	0.0884	0.0862	0.0022–
0.2000	0.2000	0.8195	0.8341	0.0146+

It is obvious, therefore, that neither the method of Rammelsberg nor that of Mayer may justly claim to be what a good process should be, accurate and rapid; and in the dilemma many chemists have been inclined to accept, with Bunsen,[1] the inherent disadvantage of an indirect process, and in a mixture of sodium and lithium chlorides calculate the percentage of each from the known weight of the mixture and its contents in chlorine, and in a mixture of the three chlorides calculate the percentage of each from the known weight of the mixture and the determined contents in chlorine and potassium. Here again, however, as in Rammelsberg's process, the difficulty of bringing the chlorides to a definite condition for weighing without decomposing the lithium chloride is an obstacle; and in case potassium is to be separated from large amounts of lithium by precipitation as potassio-platinic chloride, the concurrent precipitation of a similar salt of lithium, to which Jenzsch[2] has directed attention, may be the occasion of inexactness. So, the intrinsic unsatisfactoriness of indirect methods quite aside, it appears that in following Bunsen we have by no means all that is to be desired in an analytical method.

In looking about for better means for the separation of lithium from sodium and potassium, certain preliminary experiments on the behavior of the chlorides of these elements toward amyl alcohol gave very encouraging indications, and subsequent quantitative tests have borne out the hope that a successful method of separation might be based upon these relations.

In amyl alcohol the chlorides of sodium and potassium are highly insoluble, lithium chloride dissolves freely, and the attraction of amyl alcohol for water is so slight and its boiling point so far above 100° C. that the latter may be expelled without difficulty by the aid of gentle heating.

When amyl alcohol is poured into a solution of lithium chloride in water the liquid forms two layers, the aqueous solution of the salts at the bottom and the amyl alcohol now carrying a little water above. With the application of heat, the water evaporates slowly, then boils, and, passing through the alcohol, escapes, until toward the end of the operation the residual lithium chloride collects in a viscous globule and

---

of lithium gave a residue of 68.40." I have taken this to mean that in all three experiments 0.2 grm. of sodium chloride and 0.2 grm. of potassium chloride were employed with the different proportions of lithium chloride indicated for each experiment. At all events, if this is not the meaning of the language made use of, it is difficult to see a definite value in the experiments.

[1] Ann. Chem. und Pharm., CXXII, p. 348.

[2] Pogg. Ann., CIV, p. 102.

finally dissolves, with the exception of a slight incrustation. If now the alcohol is cooled and a drop of strong hydrochloric acid is added and brought in contact with the deposit and the boiling repeated, the solution is complete. This deposit I take to be lithium hydrate, resulting from the decomposition of the chloride by the protracted action of water at a temperature near its boiling point. The small amount of water which is added in and with the hydrochloric acid seems to exert no unfavorable influence, but rather to be beneficial in hastening the solution of the residue by securing immediate and sufficient contact.

In hot amyl alcohol, lithium chloride appears to be a little more soluble than in the same reagent at ordinary temperatures, but the solubility under the latter condition only was determined. By boiling the solution until turbidity began to show, cooling, filtering, and then evaporating a known volume of the concentrated solution to dryness and weighing the residue after converting it to the sulphate, it was found that one part of lithium chloride was held dissolved in the cold in about fifteen parts of amyl alcohol, 10 $cm.^3$ of the solution containing in the mean 0.66 grm. of the chloride.

When aqueous solutions of sodium chloride or potassium chloride are treated with amyl alcohol and boiled, the water disappears, as before, leaving first a globule of the concentrated solution and finally the crystalline salts. On continuing the boiling until a thermometer dipped in the liquid indicates the temperature at which the alcohol boils by itself, a slight additional precipitation, doubtless due to the expulsion of the water retained by the alcohol up to this point, takes place upon the walls of the containing vessel. The results of quantitative tests of the solubility of sodium and potassium chlorides are given in the following tables. The strengths of the solutions of sodium chloride and potassium chloride were determined by evaporating weighed portions in a platinum crucible and drying at a temperature considerably below the melting point of the salt, and weighing. The solution of lithium chloride was standardized by treating a weighed portion with sulphuric acid in excess, evaporating, igniting at red heat, and weighing. The standards were fixed by experiments (1) to (9).

	Weight of solution of NaCl taken.	Weight of NaCl found.	Weight of NaCl in 10 grm. of solution.	Mean.
	grm.	grm.	grm.	grm.
(1)	10.7110	0.1072	0.1001	
(2)	10.9419	0.1097	0.1003	0.1002
(3)	10.9325	0.1097	0.1003	

	Weight of solution of KaCl taken.	Weight of KaCl found.	Weight of KaCl in 10 grm. of solution.	Mean.
	grm.	grm.	grm.	grm.
(4)	9.3045	0.1744	0.1874	
(5)	10.7225	0.2006	0.1871	0.1872
(6)	11.1974	0.2096	0.1872	

	Weight of solution of LiCl taken.	Weight of Li_2SO_4 found.	Weight of LiCl in 10 grm. of solution.	Mean.
	grm.	grm.	grm.	grm.
(7)	10.9280	0.1635	0.1156	
(8)	11.1480	0.1665	0.1153	0.1154
(9)	10.8790	0.1626	0.1154	

To determine the solubility of sodium chloride and potassium chloride in amyl alcohol, portions of the test solutions were weighed out, evaporated to a convenient bulk in platinum crucibles of 100 cm.^{3} capacity, amyl alcohol was added, the water expelled by boiling, and the heating continued for some minutes after the thermometer in the liquid indicated 132° C., the boiling point of the alcohol employed. The liquid was then decanted with care and the residue dried at a temperature below its melting point and weighed. When the chlorides are precipitated in the manner described, the deposit generally adheres so closely and such particles as do remain loose settle so well that the supernatant liquid may be decanted to the end without appreciable transportation of the insoluble residue. For the sake of perfect security, however, in this part of the manipulation the decanted liquid was filtered under gentle pressure upon asbestus, with the aid of the device which I have previously described for such purposes,[1] and, after gentle heating, the increase in weight of the felt and the containing perforated crucible was added to the weight of the residual salt. In no case did this increase exceed a few tenths of a milligram and often could not be detected.

As a source of heat, a bath in which the sand of the sand bath is replaced by smooth asbestus board is a convenience, or a piece of asbestus board simply, about 30 cm. square, supported by a broad tripod and heated under the middle by a Bunsen burner, answers equally well to secure every gradation of heat without danger of igniting the evaporated alcohol.

As a control upon the results obtained by weighing the residue as described, the filtrate was evaporated in a large platinum crucible and the residue thus left gently heated and weighed. Though the evaporation be conducted with extreme care, the residue is almost sure to show some blackening, due to the carbonization of matter carried by the alcohol, which will not disappear entirely without the application of a degree of heat which the salts cannot bear without danger of volatilization. The weight of the residue from the amyl alcohol itself is small, one portion of 50 cm.^{3} yielding 0.0003 grm. and its mate 0.0007 grm., so that the data obtained by the evaporation of the filtered alcohol of the experiments, if not quite so trustworthy as the former testimony,

[1] Proc. Am. Acad., Vol. XIII, p. 342.

may nevertheless serve the purpose of a very close control. Both sets of data are given in the following table:

	Weight of NaCl taken.	Total weight of NaCl found.	Weight found in residue.	Weight found in solution.	Volume of residual amyl alcohol.
	grm.	grm.	grm.	grm.	cm.^{3}
(10)	0.1062	0.1067	0.1043	0.0024	52
(11)	0.1043	0.1047	0.1024	0.0023	46
(12)	0.1024	0.1030	0.1003	0.0027	51
(13)	0.1003	0.1008	0.0983	0.0025	45

Reducing these figures to a common level to show the action of the same amount of amyl alcohol in every case we have:

	Loss of NaCl to 100 cm.^{3} of amyl alcohol.	Mean.	Weight of NaCl found in solution in 100 cm.^{3} of amyl alcohol.	Mean.
	grm.		grm.	
(10)	0.0037	grm. 0.0041	0.0046	grm. 0.0051
(11)	0.0041		0.0050	
(12)	0.0041		0.0053	
(13)	0.0044		0.0055	

	Weight of KCl taken.	Total weight of KCl found.	Weight found in residue.	Weight found in solution.	Volume of residual amyl alcohol.
	grm.	grm.	grm.	grm.	cm.^{3}
(14)	0.2091	0.2093	0.2074	0.0019	35
(15)	0.2074	0.2078	0.2059	0.0019	36
(16)	0.2059	0.2059	0.2040	0.0019	32
(17)	0.2040	0.2041	0.2015	0.0026	45

Derived from these figures we have:

	Loss of KCl to 100 cm.^{3} of amyl alcohol.	Mean.	Weight of KCl found in solution in 100 cm.^{3} of amyl alcohol.	Mean.
	grm.		grm.	
(14)	0.0049	grm. 0.0051	0.0054	grm. 0.0056
(15)	0.0041		0.0053	
(16)	0.0059		0.0059	
(17)	0.0056		0.0058	

From these figures it appears that the total weight of chloride found is always a little greater than that taken, the mean increase being 0.0005 grm. for sodium chloride and 0.0002 grm. for potassium chloride. It appears also that the residue left by the evaporation of the decanted and filtered amyl alcohol is greater than the loss put upon the chloride by the treatment: in the case of sodium chloride 0.0005 grm., in the mean, for every 50 cm.^{3} of amyl alcohol, which is about the quantity employed in the experiments; for potassic chloride 0.0002 grm., in the mean, for 40 cm.^{3} of amyl alcohol, which is approximately the quantity used in that case. It will be seen, therefore, that there exists for both salts an exact coincidence between the mean total excess found and the difference between the figures which indicate the solubility of the salts for the two methods of determination; and, taking this fact in conjunction with the results of the evaporation of amyl alcohol in blank (the mean residue being 0.0004 grm. for 40 cm.^{3}, and 0.0005 grm. for 50 cm.^{3}), it seems to be brought out pretty clearly that the former set of figures represents more exactly the solubility of the salts, though the difference between the two series is not great. Resting, then, upon the former determinations, the solubility of sodium chloride may be taken as 0.0041 grm. in every 100 cm.^{3} of anhydrous amyl alcohol, or one part in 30,000 parts by weight; and the solubility of potassium chloride, a little greater, is 0.0051 grm. to 100 cm.^{3} of amyl alcohol, or one part in 24,000 by weight.

The conditions under which the salts are acted upon are such as should insure the complete saturation of the solvent, and in this connection it is interesting to note that for the quantities of material employed the discrepancy between comparable figures never exceeds 0.0005 grm.

In experiments (10), (11), and (14), (15), the alcohol was decanted and filtered at once while hot; in (12), (13), and (16), (17), it was cooled to 30° C. before decanting; so it appears that the solubility of the salts is not influenced by changes of temperature within the range from 30° C. to 132° C.

Used simply to wash the precipitate, amyl alcohol cannot, of course, exert an effect at all comparable with that manifested in the experiments which have been described, but to know just what this action may be is important. Experiments (18) to (22) were undertaken, therefore, to elucidate this point.

Weighed amounts of the test solutions were evaporated nearly to saturation in small glass beakers, amyl alcohol added, and, as in the previous experiments, the whole heated until the salt had deposited and the residual alcohol had boiled quietly for some minutes at its ordinary boiling point, the liquid decanted, filtered under gentle pressure by means of a weighed perforated crucible and felt of asbestus, the filtrate measured, the residue dislodged with the aid of a rubbing-rod and transferred to the crucible and washed with anhydrous amyl alcohol, the washings being collected and measured. The crucible and contents were dried over a free flame turned low, so that the heat should not reach the melting point of the chlorides.

	Weight of NaCl taken.	Weight of NaCl found.	Weight of NaCl found, corrected for solubility in residual amyl alcohol.	Error of corrected weight of NaCl found.	Volume of residual amyl alcohol.	Volume of amyl alcohol in washings.
	grm.	grm.	grm.	grm.	cm.^{3}	cm.^{3}
(18)	0.0947	0.0937	0.0947	0.0000	24	44
(19)	0.1080	0.1074	0.1083	0.0002+	19	53

	Weight of KCl taken.	Weight of KCl found.	Weight of KCl found, corrected for solubility in residual amyl alcohol.	Error of corrected weight of KCl found.	Volume of residual amyl alcohol	Volume of amyl alcohol in washings.
	grm.	grm.	grm.	grm.	cm.³	cm.³
(20)	0.1846	0.1837	0.1847	0.0001+	20	60
(21)	0.1964	0.1946	0.1961	0.0003—	30	45
(22)	0.1857	0.1839	0.1854	0.0003—	30	60

These results show very plainly that the solvent effect of anhydrous amyl alcohol used for washing under the conditions described is trifling in the extreme, and may be neglected utterly providing the amount of the washing is not altogether disproportionate to the needs of the case.

We pass next to the consideration of the separation of the chlorides of sodium and potassium from lithium chloride. Weighed portions of the test solutions were concentrated and treated with amyl alcohol in the manner described until the precipitated salt was entirely free from water and the supernatant alcoholic solution of the lithium chloride boiled constantly at a point not far from that of the amyl alcohol employed. Then the liquid was cooled, a drop or two of strong hydrochloric acid was added in accordance with the evident suggestion of the preliminary experiments previously mentioned, and heat was again applied until the boiling had continued, as before, for some minutes at one point. The filtration, washing, drying, and weighing of the residue were effected as in experiments (18) to (22). In those of the experiments in which the lithium salt in solution was also determined, the end was accomplished by evaporating the filtrate and washings to dryness, treating the residue with sulphuric acid, and igniting and weighing as lithium sulphate. In the following table the weight of insoluble chloride actually found is given in one column, and this weight, corrected according to the data previously determined for the solubility of the chloride in the residual amyl alcohol, appears in the column adjoining. So also the weight is given of the lithium sulphate actually found, and an adjacent column contains the result of correcting this weight for the accompanying sodium or potassium sulphate, or both, upon the hypothesis that these salts are neutral sulphates after the ignition. In the case of quantities so minute the error which is introduced by such an assumption cannot be considerable, and in relation to this point Dittmar[1] maintains that comparatively large amounts of acid sodium or potassium sulphate may be reduced to the neutral salt by ignition simply. The figures of the column showing the weights of lithium chloride found are derived by calculation from the weights of lithium sulphate actually

[1] Report on researches into the composition of ocean water, collected by H. M. S. Challenger during the years 1873-1876, p. 18.

found. The other headings of the table are sufficiently intelligible without further explanation.

	Weight of NaCl taken.	Weight of NaCl found.	Weight of NaCl found, corrected for solubility in amyl alcohol.	Error in weight of NaCl found.	Error in corrected weight of NaCl found.	Volume of amyl alcohol used. Residual.	Volume of amyl alcohol used. Total.
	grm.	grm.	grm.	grm.	grm.	$cm.^3$	$cm.^3$
(23)	0.1089	0.1092	0.1095	0.0003+	0.0006+	7	70
(24)	0.1084	0.1085	0.1090	0.0001+	0.0006+	12	80
(25)	0.1074	0.1067	0.1074	0.0007−	0.0000	18	90

	Weight of LiCl taken.	Weight of Li_2SO_4 found.	Weight of LiCl found.	Corrected weight of LiCl found.	Error in weight of LiCl found.	Error in corrected weight of LiCl found.
	grm.	grm.	grm.	grm.	grm.	grm.
(23)	0.1298	0.1682	0.1299	0.1296	0.0001+	0.0002−
(24)	0.1227	0.1592	0.1230	0.1225	0.0003+	0.0002−
(25)	0.0116	....	....	....	....	....

	Weight of KCl taken.	Weight of KCl found.	Weight of KCl found, corrected for solubility in amyl alcohol.	Error in weight of KCl found.	Error in corrected weight of KCl found.	Volume of amyl alcohol used. Residual.	Volume of amyl alcohol used. Total.
	grm.	grm.	grm.	grm.	grm.	$cm.^3$	$cm.^3$
(26)	0.2051	0.2036	0.2053	0.0015−	0.0002+	34	100
(27)	0.2022	0.2013	0.2032	0.0009−	0.0010+	37	100
(28)	0.2109	0.2096	0.2104	0.0013−	0.0005−	16	100
(29)	0.0984	0.0970	0.0980	0.0014−	0.0004−	20	90

	Weight of LiCl taken.	Weight of Li_2SO_4 found.	Weight of LiCl found.	Corrected weight of LiCl found.	Error in weight of LiCl found.	Error in corrected weight of LiCl found.
	grm.	grm.	grm.	grm.	grm.	grm.
(26)	0.1256	0.1638	0.1265	0.1248	0.0009+	0.0008−
(27)	0.1287	0.1677	0.1296	0.1277	0.0009+	0.0010−
(28)	0.0113	....	....	....	....	....
(29)	0.0113	....	....	....	....	....

	Weight of NaCl taken.	Weight of KCl taken.	Weight of NaCl+KCl found.	Corrected weight of NaCl+KCl found.	Volume of amyl alcohol used. Residual.	Volume of amyl alcohol used. Total.
	grm.	grm.	grm.	grm.	$cm.^3$	$cm.^3$
(30)	0.1053	0.1031	0.2064	0.2084	22	100
(31)	0.1051	0.0945	0.1988	0.2003	16	80

	Weight of LiCl taken.	Error in weight of NaCl + KCl found.	Error in corrected weight of NaCl + KCl found.
	grm.	grm.	grm.
(30)	0.0113	0.0020−	0.0000
(31)	0.0113	0.0008−	0.0007+

It will be noticed that in experiments (23), (24), (26), and (27) the corrected error in the weight of the insoluble chloride has a positive value, ranging from 0.0002+ grm. to 0.0010+ grm., with a mean of 0.0006+ grm.; and that in experiments (25), (28), (29), (30), and (31), the mean error is negative, amounting to less than 0.0001 – grm., with a range from 0.0005 – grm. to 0.0007+ grm.

The point of difference between these two series of experiments is the amount of lithium chloride introduced, only a tenth of that used in the former being employed in the latter. It is plain that, when we are dealing with the larger amount, a larger portion tends to remain behind with the insoluble chloride; and here again we meet, though to a degree comparatively harmless, the inclination of lithium chloride to yield chlorine and pass to the form of lithium hydrate. When the lithium chloride is present in small amount, as in the latter group of experiments, there can be little left undissolved; and the spectroscope confirms the evidence of the figures of analysis as to the perfectness of the separation by showing in such cases either no lithium at all or merely fugitive traces. If a single precipitation is sufficient to effect a satisfactory separation of the insoluble chlorides from small amounts of lithium chloride, it is natural to suppose that a repetition of the precipitation would be beneficial in treating larger quantities of lithium chloride.

Experiments (32) to (37) illustrate the effect of a double precipitation. The chlorides were brought to filtration as before, the liquid was decanted as completely as possible, the precipitate washed slightly by decantation and redissolved in a little water, and the round of boiling, filtering, drying, and weighing carried to the end as before, care being taken to repeat the treatment with a drop of hydrochloric acid during the process of boiling. The two portions of residual amyl alcohol were measured apart, as well as the washings.

	Weight of NaCl taken.	Weight of NaCl found	Corrected weight of NaCl found.	Error in weight of NaCl found.	Error in corrected weight of NaCl found.	Volume of amyl alcohol used. Residual. I.	II.	Total.
	grm.	grm.	grm.	grm.	grm.	cm.³	cm.³	cm.³
(32)	0.1166	0.1163	0.1169	0.0003–	0.0003+	8	8	150
(33)	0.1139	0.1127	0.1132	0.0012–	0.0007–	5	7	150

	Weight of LiCl taken.	Weight of Li_2SO_4 found.	Weight of LiCl found.	Corrected weight of LiCl found.	Error in weight of LiCl found.	Error in corrected weight of LiCl found.
	grm.	grm.	grm.	grm.	grm.	grm.
(32)	0.1287	0.1662	0.1284	0.1280	0.0003–	0.0007–
(33)	0.1347	0.1759	0.1359	0.1353	0.0012+	0.0006+

	Weight of KCl taken.	Weight of KCl found.	Corrected weight of KCl found.	Error in weight of KCl found.	Error in corrected weight of KCl found.	Volume of amyl alcohol used. Residual. I.	II.	Total.
	grm.	grm.	grm.	grm.	grm.	cm.³	cm.³	cm.³
(34)	0.1155	0.1142	0.1152	0.0013–	0.0003–	10	10	100
(35)	0.1034	0.1017	0.1028	0.0017–	0.0007–	10	12	200
(36)	0.1914	0.1905	0.1912	0.0009–	0.0002–	3	11	90
(37)	0.1953	0.1939	0.1950	0.0014–	0.0003–	4	18	110

	Weight of LiCl taken.	Weight of Li_2SO_4 found.	Weight of LiCl found.	Corrected weight of LiCl found.	Error in weight of LiCl found.	Error in corrected weight of LiCl found.
	grm.	grm.	grm.	grm.	grm.	grm.
(34)	0.1125	0.1475	0.1139	0.1128	0.0014+	0.0003+
(35)	0.1251	0.1649	0.1274	0.1162	0.0023+	0.0011+
(36)	0.1263	......	......	......	....	....
(37)	0.1282	......	......	......	....	....

Thus it appears that, in the separation of the insoluble chlorides from the larger amounts of lithium chloride, the residue of two precipitations is substantially free from lithium.

For the sake of bringing the data in hand more directly into comparison, the corrected errors of the preceding determinations are tabulated again in the following statement:

No. of experiment.	Chloride.	Corrected error of insoluble chloride—			Error in corrected weight of LiCl.	Approximate mean error of LiCl.
		Precipitated once from about 0.13 grm. of LiCl.	Precipitated once from about 0.013 grm. of LiCl.	Precipitated twice from about 0.13 grm. of LiCl.		
		Grm.	*Grm.*	*Grm.*	*Grm.*	*Grm.*
(23)	NaCl	0.0006+	....	....	0.0002−	0.0005−
(24)	"	0.0006+	....	....	0.0002−	
(26)	KCl	0.0002+	....	....	0.0008−	
(27)	"	0.0010+	....	....	0.0010−	
(25)	NaCl	....	0.0000	....	....	
(28)	KCl	....	0.0005−	....	....	
(29)	"	....	0.0004−	....	....	
(30)	NaCl+KCl ...	....	0.0000	....	....	
(31)	" "	....	0.0007+	....	....	
(32)	NaCl	....	....	0.0003+	0.0007−	0.0003+
(33)	"	....	....	0.0007−	0.0006+	
(34)	KCl	....	....	0.0003−	0.0003+	
(35)	"	....	....	0.0007−	0.0011+	
(36)	"	....	....	0.0002−	....	
(37)	"	....	....	0.0003−	....	
	Approx. mean.	0.0006+	0.00004−	0.0003−		

Few processes in analytical chemistry are capable of yielding results more exact than these. The separation of from 0.1 grm. to 0.2 grm. of sodium or potassium chloride from a tenth of its own weight of lithium chloride is practically perfect in one operation, and from its own weight of lithium chloride the parting may be effected satisfactorily by two precipitations.

The points to be observed in executing the method may be recapitulated as follows:

To the concentrated solution of the chlorides, amyl alcohol is added and heat is applied, gently at first to avoid danger of bumping, until the water disappearing from solution and the point of ebullition rising and becoming constant for some minutes at a temperature which is approximately that at which the alcohol boils by itself, the chlorides of sodium and potassium are deposited and lithium chloride is dehydrated and taken into solution. At this stage in the operation the liquid is cooled and a drop or two of strong hydrochloric acid is added to reconvert traces of lithium hydrate in the deposit, and the boiling is continued until the alcohol is again free from water. If the amount of lithium chloride present is small it will now be found in solution, and the chlorides of sodium and potassium will be in the residue, excepting the traces, for which correction will be made subsequently. If, however, the weight of lithium chloride present exceeds ten or twenty milligrams, it is advisable at this point, though not absolutely essential to the attainment of fairly correct results, to decant the liquid from the residue, wash the latter a little with anhydrous amyl alcohol, dissolve in a few drops of water, and repeat the separation by boiling again in amyl alcohol. For washing, amyl alcohol previously dehydrated by boiling is to be used and the filtrates are to be measured apart from the washings. In filtering it is best to make use of the perforated crucible and asbestus felt and apply gentle pressure. The crucible and residue are ready for the balance after drying for a few minutes directly over a flame turned low. The weight of insoluble chlorides actually obtained in this manner is to be corrected by the addition of 0.00041 grm. for every 10 cm.^{3} of amyl alcohol in the filtrate, exclusive of washings, if the insoluble salt is entirely sodium chloride, 0.00051 grm. for every 10 cm.^{3} if potassium chloride constitutes the residue, and, if both sodium and potassium chloride are present, 0.00092 grm.; but, as in the experiments described, the entire correction may in any case be kept within narrow limits, if due care be given to the reduction of the volume of residual alcohol before filtration. The filtrate and washings are evaporated to dryness, treated with sulphuric acid, the excess of the latter is driven off, and the residue ignited to fusion and weighed. From the weight thus found the subtraction of 0.00050 grm. is to be made if sodium chloride constitutes the precipitate, 0.00059 grm. if potassium chloride alone is present in the residue, and 0.00109 if both of these chlorides are present, for every 10 cm.^{3} of filtrate, exclusive of washings.

Amyl alcohol is not costly, the manipulations of the process are easy, and the only objectionable feature—the development of the fumes of amyl alcohol—is one which is insignificant when good ventilation is available.

The process has been used for some months frequently and successfully, by others as well as myself, for the estimation of lithium in waters and minerals.

In this connection it seems best to include the record of certain experiments looking to the separation of the chlorides of sodium and potassium from the chlorides of magnesium and calcium. The behavior of magnesium chloride toward amyl alcohol is of interest, both with reference to the problem of separating sodium and potassium from lithium and magnesium when the latter are associated and as concerns the parting of the alkalies from magnesium alone — a matter which is by no means perfectly simple — and experiments (38) to (41) touch upon this topic.

The chlorides of sodium and potassium were weighed, as before, in solution; the magnesium chloride was obtained by dissolving in hydrochloric acid the oxide specially prepared and weighed as such. The process of treatment was identical with that just described for the separation of the chlorides of potassium and sodium from lithium chloride.

	Weight of NaCl taken.	Weight of KCl taken.	Weight of NaCl+KCl found.	Corrected weight of NaCl+KCl found.	Volume of amyl alcohol used. Residual. I.	II.	Total.
	grm.	grm.	grm.	grm.	cm.³	cm.³	cm.³
(38)	0.1030	0.1064	0.2079	0.2100	23	..	120
(39)	0.0967	0.1024	0.1976	0.2006	33	..	100
(40)	0.1030	0.1073	0.2071	0.2093	13	11	100
(41)	0.1053	0.1093	0.2114	0.2142	12	18	100

	Weight of MgO taken.	Error in weight of NaCl+KCl found.	Error in corrected weight of NaCl+KCl found.
	grm.	grm.	grm.
(38)	0.1000	0.0015−	0.0006+
(39)	0.1000	0.0015−	0.0015+
(40)	0.1000	0.0032−	0.0010−
(41)	0.1000	0.0032−	0.0004−

The residues of experiments (38) and (39), in which the separation was made by a single precipitation, carried traces of magnesia; those of (40) and (41), in which two precipitations were introduced, were found to contain in the one case no magnesia and in the other an unweighable trace. These results point out a method by which the chlorides of sodium and potassium may be obtained free from magnesia, while the small amounts of the former which pass into solution with the magnesium chloride are capable of accurate estimation; and there seems to be no reason why the separation of these alkaline chlorides from magnesium chloride and lithium chloride occurring together should not be effected in one operation, and the parting of the latter salts brought about by the familiar method of precipitating the magnesium in the cold as ammonium-magnesium phosphate.

Experiments (42) to (47), upon the separation of sodium and potassium from calcium by the action of amyl alcohol on the chlorides, yielded the figures of the following table. The mode of treatment was identical with that of the experiments with magnesia just described, excepting only the substitution of pure calcium oxide, specially prepared, for magnesium oxide.

	Weight of NaCl taken.	Weight of KCl taken.	Weight of NaCl+KCl found.	Corrected weight of NaCl+KCl found.	Volume of amyl alcohol used. Residual. I.	II.	Total.
	grm.	grm.	grm.	grm.	cm.^{3}	cm.^{3}	cm.^{3}
(42)	0.0859	0.1126	0.2177	0.2195	20	..	100
(43)	0.1018	0.1057	0.2217	0.2235	20	..	100
(44)	0.1096	0.0962	0.2112	0.2130	20	..	100
(45)	0.0985	0.1018	0.2113	0.2130	19	..	100
(46)	0.0914	0.1104	0.1968	0.2000	20	15	100
(47)	0.0997	0.1100	0.2080	0.2089	3	7	90

	Weight of CaO taken.	Error in weight of NaCl+KCl found.	Error in corrected weight of NaCl+KCl found.
	grm.	grm.	grm.
(42)	0.1000	0.0192+	0.0210+
(43)	0.1000	0.0142+	0.0160+
(44)	0.1000	0.0054+	0.0072+
(45)	0.1000	0.0110+	0.0127+
(46)	0.1000	0.0050−	0.0018−
(47)	0.1000	0.0017−	0.0008−

From these results it is plain that it is a far more difficult matter to dehydrate and dissolve calcium chloride than to dehydrate and dissolve either magnesium chloride or lithium chloride. The separation of the chlorides of sodium and potassium from calcium chloride cannot be accomplished, for the quantities employed in these experiments, by a single precipitation; but the repetition of the treatment is effective. In the residues of experiments (46) and (47) calcium could not be found by the test with ammonium oxalate. In a case, therefore, in which the separation of sodium and potassium from lithium, magnesium, and calcium in one operation should be desirable, the end may probably be accomplished by means of the process here described.

Certain preliminary experiments with the nitrates of the bases under discussion indicate that these are susceptible of similar separation by the action of amyl alcohol; and the wide applicability in analytical operations of the general principle involved — the dehydrating of salts by means of amyl alcohol or other liquid of high boiling point and appropriate solvent action — can scarcely be a matter of doubt.

THE INDIRECT ESTIMATION OF CHLORINE, BROMINE, AND IODINE BY THE ELECTROLYSIS OF THEIR SILVER SALTS, WITH EXPERIMENTS ON THE CONVERTIBILITY OF THE SILVER SALTS BY THE ACTION OF ALKALINE HALOIDS.

By J. EDWARD WHITFIELD.

In the absence of trustworthy methods for the direct quantitative separation of bromine and chlorine, it is usual to employ some process for the conversion of the mixed silver salts to a common condition. Both the reduction to silver by hydrogen and the conversion of the bromide to chloride by heating in an atmosphere of chlorine are attended with loss by volatilization and mechanical transfer, and the possible inaccuracy of both the processes is such that they can scarcely be considered as available for the estimation of small amounts of either constituent in the presence of large amounts of the other.

Of all such methods the electrolytic analysis of the mixed and fused silver salts as proposed by Bolley[1] and more recently introduced and tested by Kinnicutt[2] is probably the best, though according to Finkener[3] perfect decomposition is difficult to obtain by this method and there is danger of volatilization and partial change of the silver salts in the fusion.

Kinnicutt's test analyses of the fused salts show, for silver chloride and silver bromide each by itself, errors of 0.0006 – grm. to 0.0003 + grm. on amounts varying from 0.7 grm. to 1.8 grm.; and for the mixed silver chloride and bromide errors from 0.0010 – grm. to 0.0012 + grm. with a mean of 0.0006 + grm. on weights varying from 2 grm. to 2.8 grm.

These figures represent the sum of the errors from the weighing of the fused chloride to the weighing of the deposit of silver and do not include errors made in the precipitation, filtration, transfer to the crucible, and fusion.

A method in which the decomposition of the silver salts may be effected without fusion, and which would at the same time place the errors of filtration, preparation for weighing, and subsequent electrolysis at a

[1] Dingl., Pol. Jour., CLI, p. 46.
[2] Am. Chem. Jour., IV, p. 22.
[3] Rose-Finkener, Quant. Anal., II, p. 621.

minimum, seems to be desirable, and a promising line of investigation was suggested by Luckow's assertion[1] that from the solution of silver chloride in potassium cyanide the silver may be thrown down completely.

Luckow gives no figures, excepting a common mean of all determinations by the precipitation from the cyanide solution and the decomposition of the solid chloride on the negative pole of the battery under sulphuric acid; so that the first experiments were made to test the accuracy of the battery process under these conditions.

In experiments (1) to (5) silver chloride was the starting point. In (1) to (3) the freshly precipitated and carefully washed chloride was dried to a constant weight in a platinum dish, protected from the light, at a temperature of about 150° C., dissolved in potassium cyanide and electrolyzed after the addition of a little sodium hydrate, preliminary analyses having seemed to indicate that the presence of sodium hydrate affected the deposition favorably. In all subsequent experiments ammonia, which was found to be of equal service, was used instead of sodium hydrate.

In experiments (4) and (5) the chloride was converted, previous to electrolysis, into the bromide by solution in potassium cyanide, the addition of potassium bromide, and precipitation by sulphuric acid, as will be described later, and the precipitate redissolved in potassium cyanide, the object being to test the action of the battery upon the cyanide solution of the silver bromide.

	Ag Cl taken.	Silver found.	Silver calculated.	Error.
	grm.	grm.	grm.	grm.
(1)	0.1565	0.1177	0.1178	0.0001 —
(2)	1.3004	0.9785	0.9787	0.0002 —
(3)	2.2657	1.7047	1.7051	0.0004 —
(4)	0.7472	0.5618	0.5624	0.0006 —
(5)	0.2854	0.2133	0.2147	0.0014 —

These results, as far as they go, are satisfactory. Similar tests upon the electrolysis of silver bromide and silver iodide in the cyanide solution were undertaken, but it was thought advisable to combine incidentally with the tests of the battery process an examination of the method recently proposed by Maxwell-Lyte[2] for the direct conversion of silver chloride to the bromide and thence to the iodide.

Field[3] was the first to propose a quantitative conversion of silver chloride to the bromide by digesting the former in potassium bromide, and the change of the chloride or bromide to the iodide by the action of potassium iodide upon these salts. This method has been variously criticised and finally abandoned as an inaccurate process,[4] though so

[1] Dingl., Pol. Jour., CLXXVIII, p. 43.
[2] Chem. News, Vol. 49, p. 3.
[3] Jour. Chem. Soc., 10, p. 234.
[4] Rose-Finkener, loc. cit.

far as concerns the conversion of the chloride and bromide to the iodide Siewert[1] shows it to be exact.

Maxwell-Lyte's method of proceeding, depending upon identically the same principle which Field attempts to utilize, consists in the solution of the silver haloid salts in potassium cyanide, the addition of potassium bromide, the decomposition of the potassium cyanide by means of sulphuric acid, with the consequent precipitation and weighing of the silver bromide mixed with the iodide of the original mixture — the resolution of this precipitate in potassium cyanide, the addition of potassium iodide, the decomposition of the cyanide as before with sulphuric acid, with the formation of a precipitate, which is presumably pure silver iodide and to be weighed as such.

To convert the chloride to the bromide Maxwell-Lyte uses a weight of potassium bromide equal to the weight of the silver chloride taken, and, to change the bromide to the iodide, a weight of potassium iodide one and a quarter times as great as the original weight of the silver chloride.

In the following experiments these amounts have varied widely, but the proportion of alkaline haloid salts employed is given for each case in the tabular statement.

The starting point was generally freshly precipitated silver chloride, but in the last three cases pure silver, this being dissolved in nitric acid, precipitated with potassium bromide (two equivalents), and the precipitate dissolved in potassium cyanide, converted to the iodide in the manner described, and weighed, the object of this being to test the convertibility of silver bromide to silver iodide.

In most cases the final precipitate after weighing was electrolyzed, so as to have a more perfect control upon the results of the conversion process, and at the same time to test the battery method additionally.

The bromide and iodide of silver were precipitated hot from dilute solutions, which were cooled and allowed to stand over night to settle before filtering.

Filtrations were made by the use of the Gooch crucible with gentle pressure. The silver salts were dried directly over a low Bunsen flame at a temperature far below the melting point, and dissolved, after weighing, by introducing crucible and asbestus into a strong solution of potassium cyanide and heating, the time necessary for the solution varying from a few minutes to several hours, according to circumstances. In some cases traces of reduced silver were found with the asbestus and were recovered by treating the felt with nitric acid and washing, the filtrate and washings being added to the main solution.

The deposition of silver was made in the platinum dish of 100 cm.^{3} capacity, which held the solution, and the current found most suitable was (as Luckow originally ecommended)[2] developed by four Meidinger

[1] Zeitschr. anal. Chem., 7, p. 469.

[2] Loc. cit.

cells of large size. With solutions of the volume named and the area of the negative electrode employed, it was found advisable not to attempt to treat more than two grammes of the silver salt.

The solution was decanted immediately on the stopping of the current, or, better, siphoned off while the battery connections were still unbroken, and washed with distilled water to prevent the solvent action of the cyanide on the deposit.

	AgCl taken.	AgBr found.	AgBr calculated.	Error.	Equivalents of K Br taken.
	grm.	grm.	grm.	grm.	
(6)	0.3260	0.4227	0.4270	0.0043 —	2
(7)	0.3093	0.4023	0.4052	0.0029 —	2
(8)	1.3801	1.8041	1.8080	0.0039 —	2
(9)	0.2091	0.2723	0.2739	0.0016 —	10
(10)	0.6846	0.8909	0.8968	0.0059 —	10
(11)	1.1625	1.5202	1.5230	0.0028 —	20
(12)	1.1734	1.5310	1.5372	0.0062 —	20
(13)	0.3501	0.4553	0.4586	0.0033 —	29
(14)	0.4178	0.5468	0.5473	0.0005 —	29

	AgCl taken.	Silver found.	Silver calculated.	Error.
	grm.	grm.	grm.	grm.
(6)	0.3260	0.2443	0.2453	0.0010 —
(7)	0.3093	......	......	......
(8)	1.3801	1.0385	1.0386	0.0001 —
(9)	0.2091	......	......	......
(10)	0.6846	0.5137	0.5152	0.0015 —
(11)	1.1625	......	......	......
(12)	1.1734	0.8829	0.8831	0.0002 —
(13)	0.3501	0.2634	0.2634	0.0000
(14)	0.4178	......	......	......

	AgCl taken.	AgI found.	AgI calculated.	Error.	Equivalents taken of K I.
	grm.	grm.	grm.	grm.	
(15)	0.6996	1.1451	1.1456	0.0005 —	2
(16)	0.7587	1.2429	1.2424	0.0005 +	2
(17)	0.6710	1.0992	1.0988	0.0004 +	10
(18)	0.2515	0.4118	0.4118	0.0000	10
(19)	0.6501	1.0646	1.0646	0.0000	10

	AgCl taken.	Silver found.	Silver calculated.	Error.
	grm.	grm.	grm.	grm.
(15)	0.6996	0.5255	0.5265	0.0010 —
(16)	0.7587	0.5691	0.5710	0.0019 —
(17)	0.6710	0.5042	0.5050	0.0008 —
(18)	0.2515	0.1892	0.1892	0.0000
(19)	0.6501	0.4892	0.4892	0.0000

	Silver taken.	AgI found.	AgI calculated.	Error.	Equivalent taken of K I.	Silver found.	Error.
	grm.	grm.	grm.	grm.			grm.
(20)	0.5418	1.1790	1.1789	0.0001 +	2	0.5417	0.0001 —
(21)	0.3750	0.8154	0.8159	0.0005 —	2	0.3746	0.0004 —
(22)	0.4078	0.8859	0.8873	0.0012 —	10	0.4077	0.0001 —

From these experiments it appears that the deposition of silver from the cyanide solution of the chloride, bromide, or iodide is exceptionally exact. The tendency of the process, however, is to yield low results, and yet, in spite of the multiplicity of operations through which the original material has been passed in the attempt to settle two questions at once, the deficiency is not very great, being 0.0005 grm. in the mean of eighteen determinations, with a maximum value of 0.0019 grm.

The conversion of silver chloride to silver bromide by the method proposed by Maxwell-Lyte, like its predecessor, is too imperfect to be worthy of trust, but the experiments indicate unmistakably that the change of silver chloride or silver bromide to silver iodide is sufficiently complete to afford the basis of a good analytical method.

The indirect estimation of chlorine and bromine, chlorine and iodine, or bromine and iodine in presence of one another may be effected satisfactorily, therefore, by precipitating both together as silver salts, filtering on asbestus, washing and drying at 150° C., weighing, dissolving the residue in potassium cyanide, and either electrolyzing the solution to determine the silver or precipitating the silver as iodide again, filtering upon asbestus, washing, drying, and weighing.

In a mixture of all three halogens the iodine is first to be separated by known methods, and the chlorine and bromine are to be indirectly estimated as described.

ON TWO NEW METEORIC IRONS AND AN IRON OF DOUBTFUL NATURE.

By R. B. Riggs.

THE GRAND RAPIDS METEORITE.

In the American Journal of Science (Vol. XXVIII, 3d ser., p. 297), Prof. J. R. Eastman called attention to an iron of probably meteoric origin, found near Grand Rapids, in Walker Township, Kent County, Michigan.

At the time a rough analysis was made on scanty material, identifying it as a true meteoric iron. Since then the iron has come into the keeping of the National Museum and a more careful analysis has been made, with the following results:

	Per cent.
Fe	88.71
Ni	10.69
Cu	.07
Mg	.02
P	.26
S	.03
C (combined)	.06
Graphite	.07
	99.91

The meteorite weighed originally about 52 kilograms. It is a compact mass of great apparent homogeneity, possessing a specific gravity of 7.87. One of the sections disclosed, however, a small nodule about one centimeter in diameter. This not being available for analysis, its composition remains undetermined.

Etched with nitric acid, the iron gives Widmanstättian figures very like those of the Robertson County meteorite, though of a finer character. No fracture lines were observed.

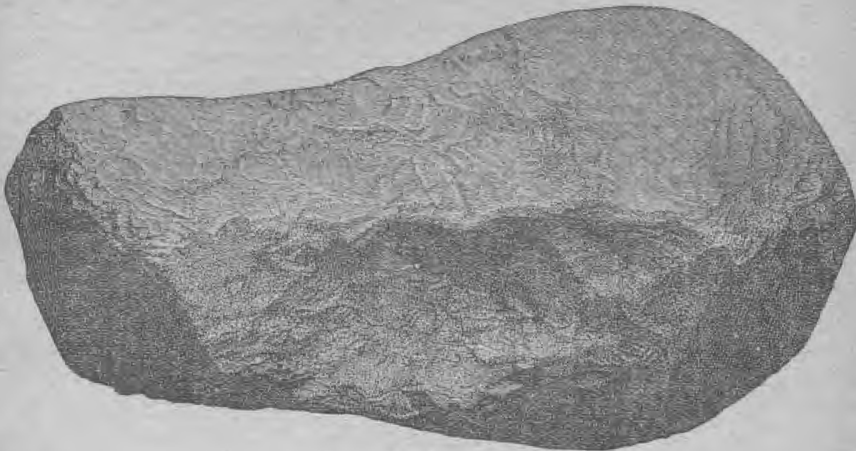


FIG. 4. Grand Rapids meteorite.

FIG. 5. Etched surface of Grand Rapids meteorite.

THE ABERT IRON.

This meteorite was found unlabeled in a collection of minerals made by the late Col. J. J. Abert, and was presented to the National Museum by his son, Mr. J. T. Abert. The iron, evidently not a fragment, weighed originally 456 grammes, and had a specific gravity of 7.89. A cross section measured 50 by 37 millimeters.

An analysis gave it the following composition:

	Per cent.
Fe	92.04
Ni	7.00
Co	0.68
P	0.08
S	0.01
C (combined)	0.02
Graphite	0.03
	99.86

Nitric acid brought out very characteristic Widmanstättian figures, of the same octahedral marking with, though somewhat coarser than, those of the Grand Rapids meteorite. The fracture is distinctly octahedral.

FIG. 6. Etched surface of Abert meteorite (actual size of section).

AN IRON OF DOUBTFUL NATURE.

This iron was found on the farm of A. L. Hodge, 3 miles southwest of New Market Station, Jefferson County, Tennessee. It is from a region full of small iron furnaces, whence have come a number of the pseudometeorites, among others the Hominy Creek, Rutherfordton, and Campbell County irons. Special inquiries were therefore made by Prof. Ira Sayles, who obtained the specimen, regarding the presence of furnaces in the vicinity. So far as could be learned, that locality was free from them. Full of cavities, the iron is characterized by great hardness, defying the use of saws. With a specific gravity of 7.61, it weighed 640 grammes. Fragments, however, had evidently been broken off from it.

The following are the results of an ana.ysis :

	Per cent.
Fe	88.27
Ni	0.76
Co	0.19
Cu	0.03
As	Trace
Mn	6.73
Mg	0.14
P	1.80
Si	0.15
C (combined)	1.46
Graphite	0.86
	100.39

Treated with nitric acid, the polished surface developed quite fine markings not unlike Widmanstättian figures.

Its high percentage in manganese is possibly an objection (not by any means all sufficient) to ascribing to it a meteoric origin. The presence of manganese, and in considerable quantities, is not so uncommon as many think. The Claiborne and Bitburg meteorites, both of unquestioned origin, contain respectively 3.24 per cent. and 4 per cent. Furthermore, while the presence of nickel and cobalt proves nothing, so large an amount of phosphorus is not common in a furnace product.

THE EFFECT OF SUDDEN COOLING EXHIBITED BY GLASS AND BY STEEL, CONSIDERED BOTH PHYSICALLY AND CHEMICALLY.[1]

By C. Barus and V. Strouhal.

§ I. THE STRAIN IMPARTED BY SUDDEN COOLING, AND ITS RELATIONS TO TEMPERATURE.

INTRODUCTION.

In Bulletin 35 we communicated a series of results on the structure of steel of a given kind, tempered hard. They showed, in general, that from the circumference to the axis of a quenched, non-filable, steel cylinder hardness continually diminishes; that the first filable strata are encountered at a distance of about 1^{cm} below the surface. Moreover, as hardness decreases, the density of the elementary conaxial cylindrical shells increases, and in proportion as the layers become more and more nearly or easily filable the density is found to approach the density of soft steel. From an examination of rods of different diameters (2^{cm} to 3^{cm}) it appears, steel of a given kind presupposed, that the hardness at a point is essentially dependent on the distance of the point below the surface. The rate at which sudden cooling takes place must be similarly conditioned. Hence it is permissible to associate the one phenomenon with the other and to state that the hardness in a given point below the surface is dependent on the rate at which cooling there takes place. This point of view is suggestive; structure investigations may be made to furnish us the best means we know for the comparison of hardness and rate of cooling.

The results cited apparently make sad havoc with physical theories of temper. They seem indeed to be fatally at variance with the usually accepted views, viz: that in hard tempered steel an abnormally dense shell is arched around an abnormally rare core, the two states of strain mutually conditioning each other. The data may even be looked upon as furnishing evidence sufficient to prove the total absence of strain. It is the object of the present section to investigate in what measure this evidence is critically sufficient; if it be insufficient, to state the nature and relations of the strain effect of quenching somewhat more clearly than we were able to do in our earlier work.

[1] Our earlier work on the iron carburets will be found in Bulletins Nos. 14, 27, and 35.

In our little book on the iron carburets[1] we endeavored to contrast the respective merits of chemical and physical theories of temper, using for this purpose all the data known to us, as well as special results of our own. The deduction seemed warranted that hardness and strain are distinct and separate properties of a tempered iron carburet;[2] that they need not necessarily coexist. Leaving therefore hardness pure to be explained chemically, we inferred that the category of electrical and magnetic phenomena exhibited by steel on passing from hard to soft are mainly referable to changes in the character and intensity of the strain which the tempered rod carries. We accepted the theory of a dense shell and a rare core as being the most satisfactory and elegant conception of the strain in question, with the proviso[3] that "it must be regarded as a mere *diagram* of the essential features of the vastly more complicated structure of the glass-hard rod." These conditions premised, we finally interpreted all variation of strain produced by annealing as the combined effect of changes of the viscosity of steel due to temperature and of interference of thermal expansion with the said strain.

The experimental question which we are endeavoring to elucidate may therefore be succinctly put as follows:

(1) With what degree of sensitiveness do the variations of the density of the rod, as a whole, indicate the corresponding variations of strain?

(2) Is it possible successively to remove layer after layer of a rod without materially changing the character and intensity of the strain which the rod is supposed to carry?

(3) In how far does the actual structure of tempered steel differ from the diagrammatic distribution of density above assumed?

(4) Does the process of sudden cooling impart strain alike in kind[4] but differing enormously in degree to all substances?

In our paper on structure we had the second and third of these points principally in mind. We were unable to obtain direct and decisive evidence of the occurence of shrinkage during the removal of shells from a hard steel rod. But since the structure of steel differs so largely with the kind of steel operated upon, we do not regard our experiments as made in sufficient number to be conclusive. An examination of the density of the elementary shells shows that the character of the density at any point regarded as a function of the distance of a point below the surface is harmonic.[5] To investigate this relation it is unfortunately necessary to make the measurements for thin ($\frac{1}{2}^{mm}$) shells. Hence the

---

[1] Bull. U. S. Geol. Surv., No. 14, p. 76, 1885.

[2] Id., pp. 103, 197

[3] Bull. U. S. Geol. Surv., No. 14, pp. 95–98

[4] We do not necessarily refer to mere volume expansion here. See Wrightson, Jour. Iron and Steel Inst., II, p. 418, 1879.

[5] Bull. No. 35, U. S. Geol. Surv., p. 32, 1886.

mean amplitude of vibration and the limits of the unavoidable errors of observation are of the same order. To discriminate between the periodic effect of temper, which may show regular or irregular periodicity, and the apparently periodic distribution of mere errors of observation is difficult and requires very nice and careful observation. In Bulletin 35 we attempt to arrive at this discrimination by making minute comparisons of the structures of rods of the same kind of steel and of the same or of different diameters. This procedure is excessively laborious; it calls for a detailed construction of the relation of the density and the position of the points along any given radius of the rod and subsequent examination of the properties which the divers diagrams have in common. We have gathered many data, but the work is as yet incomplete, and the reader desiring further information will have to be referred to Bulletin 35, where the whole subject is discussed. Experiment on the fourth of the above topics we have now in progress and shall publish later. This narrows the purposes of this paper to the consideration of the first and most important of the above points, viz: In what degree the density of a hard steel rod at different points, even when measured with all attainable accuracy, is sufficiently sensitive to represent the character, relations, and intensity of the temper strain.

DENSITY AND RESISTANCE (STRAIN) OF TEMPERED STEEL.

Experimental results.—The discussion may be appropriately commenced by an examination of the variation of density of steel successively annealed from hard to soft. Our experiments on this subject, made in some number, are detailed in Bulletin No. 27, U. S. Geological Survey, and from this we select a digest of data sufficient for the construction of the following graphic comparison, a comparison which did not fall properly within the scope of the inquiry in Bulletin No. 27, and hence was there omitted. It is necessary to reiterate that the dimensions of the steel rods used were as follows:

TABLE I.

No.	I.	II.	55 to 60 61 to 63	0.	36 to 36.
Average length of pieces (cm)	5.3	10.1	2.5	2.5	2.5
Number of pieces (cm)	1	1	21	18	72
Diameter (cm)	1.9	0.58	0.13	0.23	0.08

It was our constant endeavor to so anneal as to exclude all errors due to superficial oxidation and carburation. Whether this was accomplished remains to be seen. In Fig. 7 the temperature at which the rod was annealed is given as abscissa, the corresponding density as ordinate.

The commercial density for the respective cases is indicated by an attached *c*.

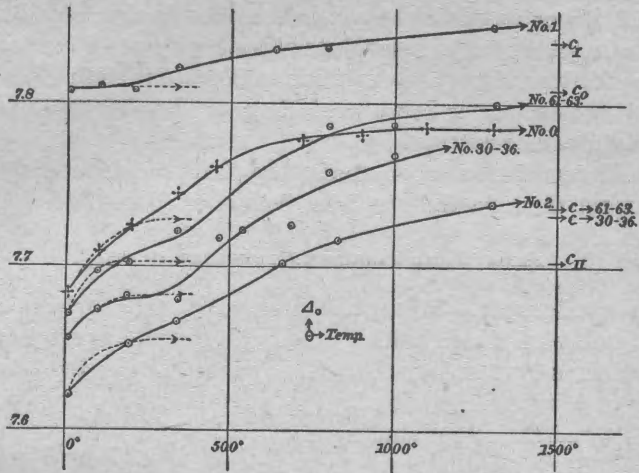


Fig. 7. Diagram showing variation of the density of steel, with temperature of annealing.

Discussion.—We advert in passing to the fact that, whereas density increases continually on passing from hard to soft, resistance passes through a pronounced minimum.

Whether we regard Δ_0 as a function of resistance or of the temperature t° at which the rod was annealed, the relations investigated lead to an important inference with an immediate bearing on our present purposes. It appears plainly that *the annealing of a rod successively from extreme hard to extreme soft does not exhibit the characteristics of a single and homogeneous phenomenon.* This annealing presents two distinct and independent phases, which merge into each other when t° corresponds to incipient redness. The graphic representation of Δ_0 varying with t° shows this transition with singular clearness. Between $t^\circ = 200$ and $t^\circ = 500$ all the loci pass through two consecutive circumflexures in such a way as to change the general and pretty uniform contours of concavity downwards into convexity downwards for the interval in question. The division of the complete phenomenon into two parts being thus suggested, we find on further inspection that the variations of the electrical constants of temper subside almost completely within the first of these parts (annealing between 0° and 350°); whereas in the second part (annealing between 350° and 1,000°) they become crowded and complex. It follows plausibly and at once that during the first of the phases under consideration we encounter the subsidence of a mechanical strain. This inference gains much in weight when we find that this strain vanishes, in the way peculiar to phenomena of viscosity, at a slowly decreasing rate, through infinite time.[1] In the sec-

[1] In other words, the temper strain vanishes just like the simple "drawn" strains imparted by the wire plate while the wires carrying them are each exposed to the prolonged action of temperature.—Bull. No. 14, U. S. Geol. Surv., p. 93.

ond phase, mechanical and chemical occurrences are superimposed and the above results do not enable us to disentangle them.

The final important deduction from the data is this, that during the first phase, in which the larger values of resistance are from two to three times the smaller values, the variation of density is slight. In the second phase we encounter large variations of density associated with small variations of resistance.

These curious relations characterize the phenomenon as a whole. We shall interpret them partially at least below.

DENSITY AND STRAINS IN TEMPERED GLASS.

Experimental results.—This result substantiates the evidence in favor of the existence of strain in hard steel adduced in our earlier papers.[1] Beyond this it shows almost conclusively that the density effect of the annealing of hard steel is out of all proportion and symmetry with the strain effect and the corresponding electrical effect. We were desirous, therefore, of studying the temper strain in substances other than steel and free from carbon. Long ago glass had suggested itself to us for this purpose.[2] We communicate in the following Table II the density effect produced by successive annealing of ordinary Prince Rupert drops. Twelve of these were in hand. Three were broken to test the strain, the remainder examined. All the drops contained included bubbles, one or more, often 0.2^{cm} to 0.3^{cm} in diameter and distributed irregularly. Usually a few large bubbles predominated. The drops moreover showed a purple coloration, which disappeared after annealing at incipient redness.[3] To anneal the drops at different temperatures we inclosed them in a test tube, cushioned upon and surrounded by carded asbestus. The end of the tube was submerged sufficiently to cover the Prince Rupert drops in boiling camphor, mercury, sulphur, &c., as given in the table. To anneal at red heat, the drops were suspended in little baskets of platinum foil, in the center of large thick clay crucibles, and then heated to the desired temperature in an assay furnace. Under all circumstances but one care was taken, to cool the drops slowly. Table II contains under "temper" the temperature and time of annealing, not including the time of cooling, however. The column m gives the weight of each drop in grammes. Variations of m are due to accidental breakage of the frail stems of the drops. Where no such breakage occurs m is constant. Δ_t is the density of the drops at t°; Δ_0, finally, is the density of the drops at 0° C., under the conditions given. Each Δ_0 is the mean of two independent determinations and is correct to within one or two units of the third place.

[1] Bull. No. 14, U. S. Geol. Surv., pp. 88–103.

[2] Wied. Ann., VII, p. 406, 1879.

[3] The color of the drops is amethystine. Mr. R. B. Riggs, of the U. S. Geological Survey, kindly analyzed the glass and found manganese.

TABLE II.—*Temper, weight, and density of quenched glass (Prince Rupert drops) successively annealed.*

No.	Temper.	m	t	Δ_t	Mean Δ_0	Remarks.
			°			
1	Quenched	1.3500	17.9	2.4336	2.4345	Bubbles; color.
		1.3501	17.0	2.4333	....	
	Annealed, 360°, 30^m (mercury)	1.3500	15.6	2.4388	2.4401	Do.
		1.3500	15.8	2.4394	....	
	Annealed, 600°, 10^m	1.3497	14.8	2.4894	2.4901	Bubbles and color vanish. Slow cooling; form of drop not changed.
		1.3496	15.3	2.4890	....	
	Annealed, red heat	1.3470	18.0	2.4901	2.4910	Slow cooling.
		1.3470	18.0	2.4896	....	
	Annealed, red heat	1.3311	18.4	2.4872	2.4883	Cooled in air.
	Annealed, red heat	1.3312	18.2	2.4904	2.4915	Cooled slowly.
2	Quenched	1.3200	17.5	2.4354	2.4364	Bubbles; color.
		1.3201	16.8	2.4354	....	
	Annealed, 360°, 30^m (mercury)	1.3201	15.7	2.4392	2.4408	Do.
		1.3200	15.8	2.4404	....	
	Annealed, 600°, 10^m	1.3191	15.1	2.4898	2.4903	Bubbles and color vanish; slow cooling; form of drop not changed.
		1.3190	15.5	2.4891	....	
	Annealed, red heat	1.3172	18.5	2.4901	2.4912	Slow cooling.
3	Quenched	1.4590	15.9	2.4364	2.4374	Bubbles; color.
		1.4590	16.0	2.4364	....	
	Annealed, 200°, 15^m (paraffine)	1.4591	15.9	2.4354	2.4364	Do.
	Annealed, 360°, 30^m	1.4590	16.5	2.4403	2.4411	Do.
		1.4590	16.9	2.4399	....	
4	Quenched	1.3305	16.0	2.4345	2.4356	Bubbles; color.
		1.3304	16.0	2.4348	....	
	Annealed, 200°, 15^m	1.3305	16.3	2.4341	2.4351	Do.
	Annealed, 360°, 30^m	1.3292	16.7	2.4369	2.4383	Do.
		1.3292	17.0	2.4378	....	
5	Quenched	1.3009	16.8	2.4333	2.4349	Do.
		1.3010	16.8	2.4344	....	
	Annealed, 200°, 1^h 30^m (camphor)	1.3009	15.9	2.4349	2.4359	Do.
	Annealed, 360°, 1^h (mercury)	1.3010	16.5	2.4390	2.4402	Do.
		1.3010	16.8	2.4394	....	
	Annealed, 450°, 30^m (sulphur)	1.3012	17.3	2.4441	2.4446	Do.
		1.3012	17.4	2.4431	....	
	Annealed, 550°, 10^m	1.2983	16.2	2.4521	2.4531	Color vanishes; slow cooling.
	Annealed, red heat	1.2982	17.5	2.4906	2.4914	Bubbles vanish; form of drop partially changod.
		1.2983	17.8	2.4900	....	
6	Quenched	1.4409	16.8	2.4312	2.4323	Bubbles; color.
		1.4408	16.9	2.4315	....	
	Annealed, 200°, 1^h 30^m (camphor)	1.4409	16.0	2.4323	2.4333	Do.
	Annealed, 360°, 1^h (mercury)	1.4409	16.7	2.4370	2.4382	Do.
		1.4409	16.9	2.4374	....	
	Annealed, 450°, 30^m (sulphur)	1.4412	17.1	2.4410	2.4422	Do.
		1.4412	17.4	2.4414	....	
	Annealed, 550°, 10^m	1.4410	16.4	2.4524	2.4534	Color vanishes · slow cooling.
	Annealed, red heat	1.4408	17.7	2.4878	2.4893	Bubbles gone; form of drop partially changed; slow cooling.
		1.4407	17.9	2.4885	....	
7	Quenched	1.4795	16.2	2.4385	2.4395	Bubbles; color.
		1.4795	17.6	2.4385	....	
8	Quenched	1.0024	16.3	2.4389	2.4395	Do.
		1.0026	17.6	2.4381	....	

TABLE II.—*Temper, weight, and density of quenched glass, &c.*—Continued.

No.	Temper.	m	t	Δ_t	Mean Δ_0	Remarks.
			°			
	Annealed, 360°, 30ᵐ (mercury)	1.0025	17.4	2.4434	2.4444	Bubbles; color.
		1.0025	17.5	2.4434	....	
	Annealed, 360°, 3ʰ (mercury)	1.0023	16.8	2.4474	2.4482	Do.
		1.0023	17.3	2.4471	....	
	Annealed, 450°, 1ʰ (sulphur)	1.0023	18.2	2.4515	2.4526	Do.
		1.0023	18.2	2.4515	....	
	Annealed, 450°, 4ʰ (sulphur)	1.0023	16.5	2.4579	2.4586	Do.
		1.0023	16.8	2.4574	....	
	Annealed, red heat	0.9982	18.5	2.4890	2.4901	Bubbles and color gone; form partially changed; slow cooling.
9	Quenched	1.2758	17.0	2.4363	2.4365	Bubbles; color.
		1.2760	17.6	2.4346	....	
	Annealed, 360°, 30ᵐ (mercury)	1.2746	17.4	2.4410	2.4423	Do.
		1.2744	17.5	2.4416	....	
	Annealed, 360°, 3ʰ	1.2745	17.0	2.4425	2.4436	Do.
		1.2745	17.4	2.4427	....	
	Annealed, 450°, 1ʰ	1.2745	18.2	2.4461	2.4472	Do.
		1.2745	18.3	2.4461	....	
	Annealed, 450°, 4ʰ	1.2727	16.7	2.4499	2.4510	Do.
		1.2727	16.8	2.4501	....	
	Annealed, red heat	1.1592	18.4	2.4918	2.4929	Bubbles and color gone; slow cooling; form of drop partially changed.

Table III, following, is constructed to facilitate a comparison of the important data. The second and third columns contain the densities of the extreme states of temper, the original quenched, "hard," and the final "soft," or thoroughly annealed state. The remaining columns contain the increments of density due to quenching, relative to the density of the soft state, the relative increments, in other words, which are retained at the divers temperatures given.

TABLE III.—*Summary showing density of Prince Rupert drops, quenched and annealed.*

No.	"Hard."[32] Δ_0.	"Soft." Δ_0.	Density increment relative to "soft," when annealed at—						
			20°.	200°.	360°.	450°.	(550°.)	(650°.)	Red heat.
1	2.4345	2.4915	−0.0229	....	−0.0207	....	....	−0.0006	−0.0002
2	2.4364	2.4912	−0.0222	....	−0.0202	....	....	−0.0004	±0.0000
3	2.4374	....	−0.0216	−0.0220	−0.0201	....	....	....	....
4	2.4356	....	−0.0223	−0.0225	−0.0212	....	....	....	....
5	2.4349	2.4914	−0.0227	−0.0223	−0.0206	−0.0188	−0.0154	....	−0.0001
6	2.4323	2.4893	−0.0229	−0.0225	−0.0205	−0.0189	−0.0144	....	+0.0007
7	2.4395	....	−0.0207	....	....	....	....	....	....
8	2.4395	2.4901	−0.0203	......	−0.0184	−0.0150	....	....	+0.0004
					−0.0168	−0.0127	....	....	....
9	2.4365	2.4929	−0.0227	......	−0.0203	−0.0184	....	....	−0.0007
					−0.0198	−0.0168	....	....	....

Discussion.—The salient features of these data are obvious from an inspection of Table III. The density effect of quenching is decidedly *negative*, the increase of specific volume is exceptionally large. Moreover, the nine[1] Prince Rupert drops examined exhibit nearly the same initial density and nearly the same final density. The approximate equality of the values Δ_0 for the soft state is easily explained. It indicates that in proportion as we bring the strain to vanish we reach the normal density of the glass. It is not so easy to account for the observation that the density of the Prince Rupert drops shows almost the same degree of equality in the hard (quenched) state. Indeed, if we take the fact into consideration that the drops invariably contain *bubbles* distributed irregularly, and without apparent relation as regards size and number, the difficulties of explanation are increased. In other words, it is an exceedingly striking and important result that the volume increase due to quenching is quite as much the same for all drops as is at all possible for the case of so complicated an operation. We are thus led to this inference: Inasmuch as bubbles are present in like total volume in each of the drops, their presence cannot be a circumstance of mere accident; they must be regarded as a normal effect, or, better, a necessary result of the operation of quenching applied to glass; they must in some very intimate way be connected with the strain which the glass globules have experienced in virtue of sudden cooling.

Retaining this very reasonable surmise in mind, we proceed to a more minute inspection of the effect of annealing the hard Prince Rupert drops. We obtain results very similar to those investigated above for steel. The density effect of annealing is decidedly positive, and is greater as temperature and time of exposure are increased. Again, we readily divide the physical effect of annealing into two parts or phases. The first of these corresponds to the annealing temperatures 0° to 500°, the other to higher temperatures. The range of temperatures corresponding to the first phase is therefore larger for glass than for steel; and if we compare Tables I and II it appears obviously that for like density effects the annealing temperatures must be chosen higher in the former case (glass) than in the latter. But the change of density encountered in both instances is small; and yet, in spite of the small density effect during the inferior stage of annealing, by far the greater intensity of strain vanishes. The drops after annealing at 200° are still explosive; if they be broken after having been annealed in boiling sulphur at 450° they are found to have lost all traces of the explosive properties which the originally quenched drops possessed. Professor O. N. Rood[2] informed us that the polarization figures could be quite wiped out by annealing such ordinary glass as exhibited them only as far as the temperature of melting zinc. We infer that at the end of the first

[1] Further (incidental) examples are given in the next section, p. 115.

[2] Results obtained by Professor Rood during his experiments with high vacua.

phase of annealing we have in hand a hollow glass globule practically free from strain.

During the second phase of the annealing phenomenon (500° to 1000°) we observe a very pronounced change of the density of the Prince Rupert drops, corresponding to the above result for steel. But the explanation is here readily at hand; at incipient redness the inclosed bubbles *disappear* or are reduced to mere specks. The large increment of density in question is therefore nothing more than an expression for the collapse of the viscous hollow globule in virtue of atmospheric pressure. This important observation enables us to interpret all the phenomena of annealing satisfactorily. It must therefore be carefully examined.

We shall endeavor to prove that the bubbles are vacua, that they are not accidental inclusions of gas or aqueous vapor. The temperature from which glass is quenched is certainly less than 1500°. The temperature at which glass is sufficiently viscous to yield easily to atmospheric pressure is certainly greater than 500°. Suppose now that the changes of volume of the bubble were the result of thermal expansion of an included gas. Let v_{1500} and v_{500} be the volumes of the gaseous inclusion at 1500° and 500°, respectively, under normal pressure. Let v_h and v_s be the volumes of the gas bubble for the quenched (hard) and annealed (soft) states. Then we deduce, a fortiori,

$$\frac{v_h}{v_s} < \frac{v_{1500}}{v_{500}} = 2.3 \qquad (1)$$

With this as a point of departure the following little digest of mean results, Table IV, has been prepared. Here m is the mean mass of all the drops examined; Δ_h, Δ_s, V_h, V_s, their mean density and total volume for the hard and the soft states, respectively; v is the mean volume; r the equivalent mean radius of the bubbles. In the second horizontal row V_h has been diminished one-half per cent., to refer all volumes to the beginning and end of the second phase of annealing.

TABLE IV.—*Mean volume relations of the Prince Rupert drops and of the hypothetical gas bubble.*

V_h	V_s	v at—		r at—		
		1500°.	500°.	1500°.	500°.	
cc.	*cc.*	*cc.*	*cc.*	*c.*	*c.*	
0.5454	0.5334	0.0120	0.0052	0.142	0.107	$\frac{v_h}{v_s}<2.3$
0.5427	0.5334	0.0093	0.0041	0.130	0.099	$\frac{r_h}{r_s}<1.3$

Mean $m = 1.3288$ g

"Hard:" Mean $\Delta_h = 2.4363 \pm 0.0008$

"Soft:" Mean $\Delta_s = 2.4911 \pm 0.0016$

Inasmuch as the values v_{500} and r_{500} are inferior limits, it is clear that, if the bubbles were gas or vapor, they would be of the same order of visibility before and after annealing. In other words, if the bubbles were gas, casual inspection would not detect a difference of their size in the "hard" (quenched) and in the "soft" drops. In the experiments, however, the bubbles all but vanish. Hence they cannot be gas.

To obtain additional assurance on this point we ground flat faces on the annealed drops Nos. 1, 5, and 8, and then measured the size of the inclusions. We found these values:

No. 1: $v_s = 0.000037^{cc}$.
No. 5: $v_s = 0.000062^{cc}$.
No. 8: $v_s = 0.000040^{cc}$.
Mean: $v_s = 0.000046^{cc}$.

From actual measurement therefore we find

$$\frac{v_h}{v_s} > 100 \tag{2}$$

a result wholly incompatible with $\frac{v_h}{v^s} < 2.4$, as derived above (Table IV). It follows conclusively that the bubbles are not accidental gas inclusions and that only an insignificant part of the variations of volume produced by quenching can be referred to thermal expansion of gas.

If the gas were aqueous vapor and if dissociation were complete, then the upper limit of (1) would have to be increased in the ratio of 3:2. This does not remove the discrepancy between (1) and (2). Moreover, since dissociation of water is only incipient at 1500°, and is not even complete at the temperature of melting platinum, the volume variation of the bubbles cannot be due to the presence of water in the bubbles.

If, on the other hand, we endeavor to explain the bubbles as vacuities[1] left by the contracting glass, we arrive at accordant and reasonable results. Let t be the temperature to which the homogenous glass drop must be heated in order that the observed mean volume of the soft state may be equal to the observed mean volume of the hard state. Then, since volume increases at an accelerated rate with temperature,

$$t < \frac{1}{3a} \frac{\varDelta_0 - \varDelta_t}{\varDelta_t} \tag{3}$$

where α is the ordinary coefficient of linear expansion of glass. By inserting the values of Table III into (3) we derive

$$t < 900°.$$

In other words, the quenched globule has retained the volume which the hot glass possessed at a temperature certainly smaller than 900°. This result taken together with the other is conclusive (see p. 112).

[1] Very analogous to Torricellian vacua.

The general result of our investigation on the process of sudden cooling, therefore, points out the fundamental importance of a rigid shell. As the material (glass or steel) cools, contraction as a whole takes place not centripetally but centrifugally, i. e., not towards the center of the figure, but away from it. So long as the interior remains liquid or viscous, the result is simple separation, commencing at points where minute air bubbles may pre-exist,[1] rather than at points of the continuity of glass. The final result is a vacuum bubble such as we have observed. In proportion as the interior becomes rigid the temper strain appears. Should the glass hold gases in solution, they would tend to escape into the vacua in question. There is probably another reason why in most instances the bubbles cannot be brought completely to vanish. Annealing reverses the whole phenomenon. The small changes of density observed in the first phase may be easily accounted for: it is probable that during these stages of annealing the rearrangement of molecules and disappearance of strain are accompanied by expansion inward toward the vacua. Hence the incommensurately small variation of mean density which accompanies the great optical effects (glass) and the great electrical effects (steel).[2] During the second stage of annealing, again, the density effect is incommensurately large; for glass it is the expression of a mere collapse, due to the atmospheric pressure. At all events the density effect (error) due to bubbles quite swallows up the density effect due to strain. Hence to represent the true relation of density and resistance or of density and annealing temperature in case of steel, it may be necessary to lower the part of the curves corresponding to the second phase of annealing by amounts equivalent to the bubble or fissure discrepancy, or else for like reasons to raise the parts of the curves corresponding to the first phase. If this be done, the circumflexures become less pronounced or disappear, and the points for the commercial soft state are more easily referred to the curves to which they belong. If, therefore, allowance be made for the distortion due to internal sensible pores, the relations become more uniform.

It is interesting to observe that glass retains the volume expansion corresponding to a temperature somewhat below 900°, whereas steel retains the volume expansion of a temperature below 400°. Similarly, the strain in steel is very perceptibly affected by annealing temperatures as low as 50°, whereas for glass the perceptible annealing effects are only incipient even at 200°. The amount of strain retained is, cæteris paribus, not merely a function of the viscosity of the material subjected to

---

[1] Prince Rupert drop No. I, heated intensely in a blast lamp and cooled in air, shows a decrement of density. This is due to the rapid cooling; for when this drop is heated and cooled in the crucible, density is again incremented. The experiment shows the tendency of glass to retain strains. During the heating to 1000° no expansion of the very small bubbles was observable.

[2] The electrical and optical criteria may be considered equally sensitive.

quenching; it must depend also on the heat conductivity of this substance. For instance, if like figures of glass and of steel be quenched alike, then at the same time and depth the thermal gradient would be much steeper in the case of glass than in the case of steel. Hence, cæteris paribus, during quenching a rigid shell is possible in the case of glass for higher temperatures of the core than in the case of steel. The sudden contraction of the shell (pressure) has a marked effect on the melting point or degree of fluidity of the core. But it is best to waive this observation here, for the want of data to interpret it.

We have finally to consider the bearing of the results of this paper on the structure of steel. The detailed similarity observed in the annealing of glass and of steel suggests the inference that the interior of hard steel may be sensibly fissured. Under all circumstances the diagrammatic structure of dense shell and rare core would be inaccurate to the extent in which these fissures are irregularly distributed. Hence the difficulty of developing the true character of the dependence of the density (δ) at any point upon the distance of this point below the surface. We are able to account in part for the quasi-harmonic relations obtained both by Dr. Fromme[1] and by ourselves.[2] While the consecutive shells are being removed by solution, periodic fluctuation of δ must result whenever fissures are invaded. If, furthermore, we take into consideration that the density effect of even great intensities of temper strain is small, it appears that the true nature of the strained structure of tempered steel may be beyond the discernment of the density method of investigation altogether. The *gross* variation of density along the radius is a carburation phenomenon.

POLARISCOPIC OBSERVATIONS.

In this place we desire to substantiate the earlier inferences of this section and to give sharper expression to them. We therefore repeat Professor Rood's experiments on the polariscopic effect of continuous annealing of cooled glass at low temperatures. Our object is merely to detect variations in the polarization figure produced by annealing or, later in our work, by the removal of superficial shells. Hence it is sufficient to examine the drops in a given fixed position between polarizing plates.[3] Disturbances due to diffuse refraction are satisfactorily eliminable by submerging the Prince Rupert drop in glycerine, the refractive power of which is nearly that of the glass. The demarkation is then distinct and the colors clear, so that the figures can easily be drawn. The necessity of grinding special faces or plates is thus fortunately obviated, for in case of the quenched drop such operations are not feasible.

[1] Wied. Ann., VIII, p. 356, 1879.

[2] Bull. No. 35, U. S. Geol., Surv. p. 36.

[3] We are indebted to Professor Hitchcock for the use of a simple but efficient reflecting polariscope, formerly the property of Professor Joseph Henry.

In the case of simple annealing, variations of the polarization figure are due to a diminution of what we may loosely call the birefractive power of the Prince Rupert drop. In the case of removal of shells, as described in the next section, variations of figure result from diminution of thickness, possibly associated with diminution of birefractive power. The solution of the drop in hydrofluoric acid does not materially interfere with its transparency. The optic observations may therefore be continued indefinitely.

Our polariscopic experiments were made with the Prince Rupert drops Nos. 1, 2, 4, 6, and Nos. 3, 5, 7, 8, 9. The first four of these were simply annealed, the remainder[1] examined after consecutive removal of shells. It is expedient to describe only the experiments with annealed drops in this section. These experiments are so striking and so easily repeated, on the one hand, and so difficult to reproduce accurately in a drawing, on the other, that the following very careful free hand sketches of the main features of the figures are here inserted, principally for purposes of record. The cuts represent Prince Rupert drops Nos. 1, 2, 4, and 6 in fixed position between nicols.

On annealing as far as $T = 200^\circ$, variations of figure are not certainly perceptible. After very long annealing at this temperature (200°) a faint influence appears, but is restricted to changes of color. It is particularly to be observed that the position and contours of the original polarization figure show a very obvious relation to the position of the included bubbles (black spots in the figure). This was the invariable result for all the Prince Rupert drops examined. It is in accord with our inference of "centrifugal" contraction,[2] discussed above. At 200°, therefore, change of strain in glass is incipient. The Prince Rupert drop, if broken, is still explosive, though perceptibly less so than the original drop.

After one hour of annealing in boiling mercury (360°) the changes of the polarization figure are obvious. The whole appearance is more diffuse, the colors bolder and broader, and the demarkation less distinct and delicate. These striking observations can only partially be reproduced in a figure. We have encountered very marked diminution of birefractive power. After seven hours of annealing in boiling mercury the evidences of diminished birefractive power have visibly increased. The figures as a whole are simpler, the coloration more gross.

Finally, after annealing in boiling sulphur (450°), the polarization figure has wholly vanished; we have in hand a hollow glass globule, free from æolotropic strain. We show on page 121 that the substance of the Prince Rupert drop is under a strain of dilatation. It is necessary to bear in mind that the isotropic part of this strain is not demonstrable by optic means. The drop annealed at 450°, however, has wholly lost its explosive character.

[1] § II, p. 116. [2] § I, p. 108.

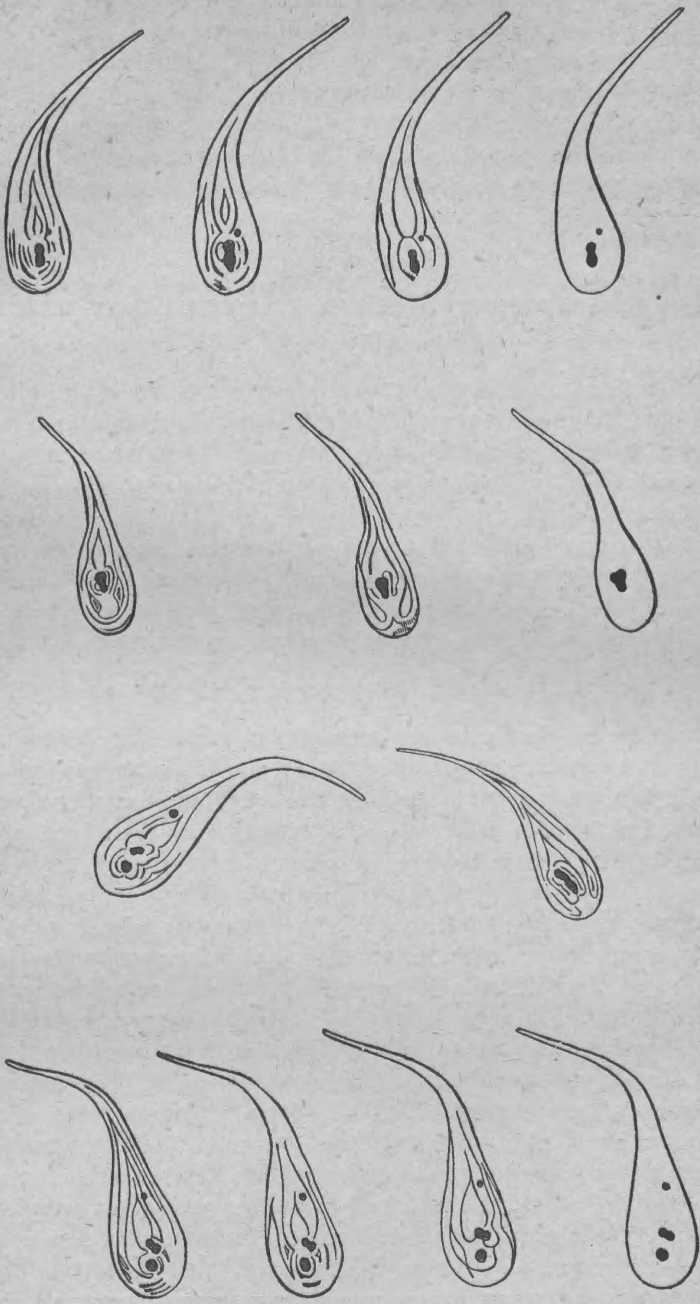


FIG. 8. Polarization figures of Prince Rupert drops.

Here we encounter the first important analogy between the optical behavior of quenched glass and the electrical behavior of quenched steel. We shall show that this parallelism extends even into details. Change of strain in glass is incipient at 200°, in steel at 50°. Change of æolotropic strain in glass is complete at a temperature certainly greater than 350° and less than 450°. The corresponding superior limit for steel cannot be so well defined. In both cases the essential dependence of the result to be reached on the temperature and the time of annealing (asymptotic relations) is the marked feature of the phenomenon.

§ II. THE STRAIN IMPARTED BY SUDDEN COOLING, AND ITS STRUCTURAL RELATIONS.

In the last section we compared the strains experienced by glass and by steel on sudden cooling by aid of the density variations observed on annealing the bodies carrying strain *as a whole.* Our purpose in this section is to investigate the density relations of consecutive similar shells of the Prince Rupert drop and the optical character of the successive cores. Availing ourselves of all the evidence adduced in our investigation at its present stage, we endeavor again to show that the optical effect of the temper strain in glass may be regarded as the precise analogon of the electrical effect of the temper strain in steel.

CERTAIN GENERAL PROPERTIES OF THE PRINCE RUPERT DROP.

It is well known that mere breakage of the tail of a Prince Rupert drop is sufficient to shatter it; the splinters fly apart with explosive violence. It is not so well known that the same drop may be dissolved in hydrofluoric acid to a mere spicule without exploding.[1] This peculiar behavior calls to mind certain properties of nitroglycerine, inasmuch as this substance may be burned off quietly in a wick but explodes on percussion. It is in keeping, moreover, with Dr. F. A. Gooch's ingenious suggestion that in the quenched globule we may possibly encounter a polymerization of the molecular structure of the annealed globule. But the fact that the strain is of an ordinary mechanical kind is proved by the observations of Table V, in which the behavior of Prince Rupert drops from which different thicknesses of shell have been removed by solution is described. In the table, "diameter" refers to the mean transverse thickness of the drops; ϑ and μ, to the thickness and the mass, respectively, of the dissolved shells. After removing a sufficient depth of shell, the residual explosive properties were tested either by crushing the reduced drop longitudinally in a vice or by striking in the same direction with a hammer.

[1] De Luynes appears to have been the first to dissolve the drop in HF (C. R. LXXVI, p. 346, 1873). He also discusses elaborately the effects produced by cutting glass with emery (C. R. LXXXI, 341, 1875). Some earlier work on the vacuum bubble is due to Reusch (Phil. Mag. (4), XXXIV, p. 166, 1867).

TABLE V.—*Explosive qualities of Prince Rupert drops.*

No.	Minutes in H. F.	Diameter.	ϑ	μ	Remarks.
		cm.	*cm.*	*g.*	
12	0	0.848	0.006	....	Shattered on breaking base of tail. Explosive tendency diminished in marked degree.
	5	0.835	....	....	
10	0	0.796	0.015	....	Shattered on being split longitudinally. Fragments partially cohere.
	10	0.766	....	....	
11	0	0.795	0.017	....	Shattered on being split longitudinally. Fragments partially cohere.
	14	0.760	....	....	
13	0	0.774	0.031	0.291	Shattered on being split longitudinally. Fragments more coherent.
	30	0.712	....	....	
3	0	0.795	0.054	0.493	Is not shattered on splitting. Conchoidal fracture.
	....	0.688	....	....	
5	0	0.825	0.053	0.491	Is not shattered on splitting. Conchoidal fracture.
	....	0.720	....	....	
7	0	0.763	0.112	0.722	Is not shattered on splitting. Conchoidal fracture.
	....	0.539	....	....	
8	0	0.791	0.117	0.752	Is not shattered on splitting. Conchoidal fracture.
	....	0.557	....	....	

The table shows that the explosive tendency of the Prince Rupert drop becomes rapidly less pronounced as the thickness of removed shell increases, that this tendency is very perceptibly impaired by the removal of less than $\frac{1}{10}^{mm}$ of shell, and that it vanishes almost wholly after the removal of $\frac{1}{2}^{mm}$ of shell. If the radius of the drop be diminished about 0.03^{cm} the particles of the fractured globule frequently cohere, and the original structure may then be inferred from the general direction and distribution of the fissures. The arrangement of the individual fragments is quite characteristic: they are found to be flat, irregular conoids, with their apices toward the line of symmetry of the drop, their bases in its surface—an arrangement something like the eye of an insect, or even more like the fruit cone of a spruce tree. In other words, the radial structure of the fissured Prince Rupert drop is very distinctly marked.[1] This proves that the original (unbroken) drop must have possessed a box-within-box structure; that, if the bubbles were symmetrically disposed, particles similarly situated with reference to the line of symmetry would be in like states of strain. But the law according to which matter is distributed from circumference to axis cannot be inferred, since the stated phenomena follow equally well both for surface dilatation and for surface compression.

All the Prince Rupert drops examined were found to scratch ordinary glass with facility; but, on removing the strain from the drops by annealing them at white heat and slowly cooling them, their hardness

[1]This structure is frequently visible in fragments of large tempered steel projectiles. I have found glass rods which on sudden heating break up into flat fragments symmetrically disposed around the axis of the rod or again into symmetric conoidal shells (see note on researches of De Luynes, on preceding page).

did not observably change. The hard quality was therefore a property of the glass itself and was not imparted by mechanical treatment. Indeed, on rubbing together a quenched and an annealed Prince Rupert drop no difference of hardness could be discerned.

GENERAL STRUCTURAL EFFECTS PRODUCED BY SUDDEN COOLING.

In Bulletin 35 we communicated a series of results on the resistance of consecutive conaxial layers of steel rods.

We there showed that it is difficult to arrive at accurate values for specific resistance in these measurements, for we encounter very small values of total resistance at the inception of the experiments and small and irregular values of sectional area at the close. Inasmuch as sections are necessarily measured too large, the values for specific resistance, S_0, are too large, and the error increases rapidly as we pass from greater to smaller diameters. The mean error of S_0 is certainly several per cent., and hence the resistances of elementary shells calculated from these data are only approximations. Nevertheless our results are important; they prove that in the case of hard rods less than 0.6^{cm} thick the values of resistance taken from circumference to axis along any radius do not perceptibly diminish. It was this curious result, apparently adverse to the hypothesis of strain, which induced us to examine the corresponding behavior of quenched glass.

The diameters, 2ρ, of Prince Rupert drops Nos. 3, 5, were successively reduced[1] as follows:

$2\rho=0.79$	0.75	0.72	0.69	0.62	0.56	cm.,
and $2\rho=0.82$	0.79	0.75	0.72	0.65	0.59	cm.

The polarization figures drawn after each of these reductions are subjoined.

The figures of each drop retained a uniform character throughout and showed no further loss of delicacy of demarkation and of colors than could be referred to diminished thickness. Unfortunately it is not easily possible to discriminate between the effect of decrement of diameter and the possibly concomitant effect of lessened birefractive power. Hence the experiments fail to indicate whether the removal of consecutive shells by solution is accompanied by changes of strain (shrinkage). If the fragments of a shattered drop, submerged in glycerine, be examined under the microscope between crossed nicols, the presence of strain in the individual splinters is quite clearly apparent. It is well to note that marked polariscopic evidence of strain remains long after the explosive properties of the Prince Rupert drops have disappeared. We infer that the electrical behavior (resistance) of the successive cores of a hard steel cylinder is not unexemplified by the optical behavior of successive cores of a Prince Rupert drop; though

[1]We desisted from further reduction of diameter in order not to enter the bubbles.

it is difficult to say whether the behavior of the partial bodies in either case (partial strains) is at all comparable with the behavior of the bodies as a whole (temper strain).

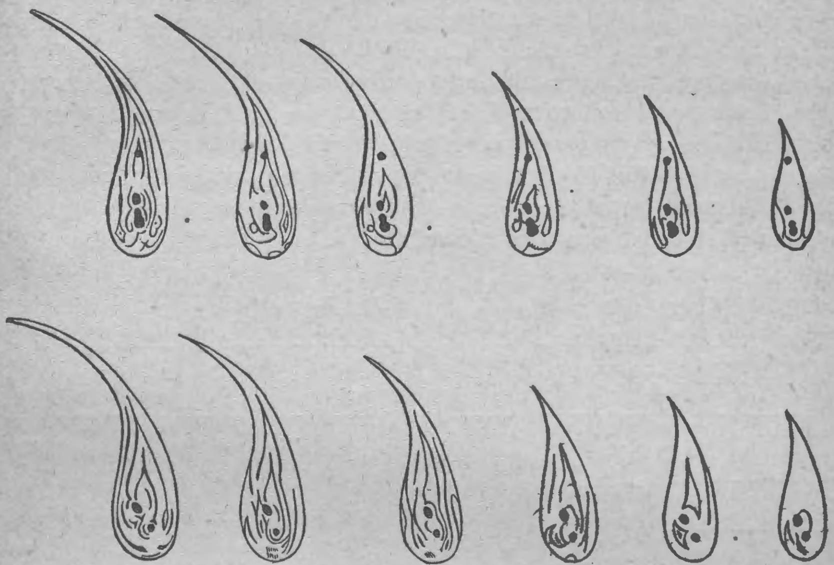


FIG. 9. Polarization figures of successive cores of Prince Rupert drops.

In this place it is well to advert to certain important data of Table IX. Having removed two shells (total thickness, $\vartheta_1+\vartheta_2=0.04^{\mathrm{cm}}$) from each of the Prince Rupert drops Nos. 10 and 11, the core densities were found to be 2.4166 and 2.4147, respectively. We then annealed them in sulphur (450°), and found for the densities of the annealed cores 2.4263 and 2.4261, respectively. This increment is quite as large as is observed when the drops are annealed *as a whole*.[1] Hence we fail to appreciate any diminution of strain due to solution. Moreover, we prove conclusively that the increment of density which is observed on annealing at the said temperature (450°) is a true increment of the density of the substance of the Prince Rupert drop; that is, not a partial collapse of the drop in virtue of atmospheric pressure. In other words, the observed *after action* is inherent in the glass itself, as we pointed out elsewhere.[2]

DISTRIBUTION OF DENSITY IN PRINCE RUPERT DROPS.

Results.—Availing ourselves of the property of the Prince Rupert drop to dissolve quietly in hydrofluoric acid, we arrived at the following results (Tables VI to X) for the variations of density along transverse radii of the drops. In these tables "diameter" denotes the mean

[1] § I, p. 104. [2] § I, p. 108.

transverse thickness of the successive cores; M and Δ_t show their mass and their density at the temperature t; Δ_0, their mean density at 0°C. Furthermore, μ, ϑ, δ, R, denote the mass, thickness, density, and mean radius, respectively, of the consecutive shells. If the n^{th} core be left after the removal of n shells, then the suffixes to the number of the drop in the first column give the history of the drop succinctly. Nearly all the measurements are made independently in duplicate. Δ_0 may be relied upon to within two units of the third place; δ, to one unit of the second place. In no case was solution carried so far as to invade the main bubbles of the drops; the drops were chosen as nearly as possible free from small bubbles. The fusions were made in platinum baskets suspended in thick closed clay crucibles. This insured very slow cooling.

TABLE VI.—*Structure of Prince Rupert drops quenched.*

Number.	Diameter.	M	Δ_t	t	Mean Δ_0	μ	ϑ	δ	Mean δ	R
	cm.	*grm.*		°C.		*grm.*	*cm.*			*cm.*
3_0	0.791	1.2577	2.435	15.5	2.4355					
	0.800	1.2576	2.434	16.0						
3_1	0.753	1.0375	2.425	16.1	2.4266	0.2202	0.020	2.483	2.478	0.387
	0.756	1.0374	2.426	16.3		0.2202		2.473		
3_2	0.730	0.8894	2.419	16.7	2.4210	0.1481	0.015	2.461	2.461	0.370
	0.720	0.8893	2.421	16.8		0.1481		2.461		
3_3	0.698	0.7651	2.411	17.0	2.4120	0.1243	0.019	2.474	2.479	0.353
	0.677	0.7650	2.411	17.3		0.1243		2.483		
5_0	0.809	1.3002	2.439	15.6	2.4400					
	0.840	1.3000	2.439	15.8						
5_1	0.762	1.0924	2.435	16.3	2.4347	0.2078	0.020	2.465	2.469	0.402
	0.810	1.0923	2.434	16.5		0.2077		2.472		
5_2	0.779	0.9317	2.428	16.5	2.4282	0.1607	0.017	2.477	2.473	0.384
	0.725	0.9318	2.428	16.6		0.1605		2.470		
5_3	0.703	0.8090	2.418	17.1	2.4181	0.1227	0.016	2.495	2.496	0.368
	0.738	0.8090	2.418	17.4		0.1228		2.498		

TABLE VII.—*Structure of Prince Rupert drops quenched.*

Number.	Diameter.	M	Δ_t	t	Mean Δ_0	μ	ϑ	δ	Mean δ	R
	cm.	*grm.*		°C.		*grm.*	*cm.*			*cm.*
7_0	0.766	1.0897	2.437	17.3	2.4386					
	0.760	1.0897	2.438	18.1						
7_1	0.750	1.0035	2.434	18.3	2.4346	0.0862	0.008	2.476	2.485	0.377
	0.743	1.0036	2.433	18.8		0.0861		2.494		
7_2	0.736	0.9254	2.431	18.6	2.4322	0.0781	0.008	2.468	2.462	0.368
	0.722	0.9254	2.431	18.7		0.0782		2.455		
7_3	0.718	0.8499	2.428	18.3	2.4288	0.0755	0.008	2.468	2.470	0.360
	0.706	0.8500	2.428	18.9		0.0754		2.473		
7_4	0.685	0.7363	2.420	19.2	2.4209	0.1136	0.017	2.480	2.482	0.347
	0.672	0.7364	2.419	20.0		0.1136		2.484		

TABLE VII.—*Structure of Prince Rupert drops quenched*—Continued.

Number.	Diameter.	M	Δ_t	t	Mean Δ_0	μ	ϑ	δ	Mean δ	R
	cm.	*grm.*		°*C.*		*grm.*	*cm.*			*cm.*
7_5	0.647	0.6148	2.410	20.0	2.4098	0.1215	0.018	2.475	2.478	0.329
	0.635	0.6148	2.408	20.2	....	0.1216	....	2.481	....	......
7_6	0.610	0.5136	2.393	19.5	2.3950	0.1012	0.019	2.497	2.489	0.311
	0.597	0.5136	2.394	20.3	....	0.1012	....	2.480	....	......
7_7	0.534	0.3672	2.362	20.2	2.3640	0.1464	0.032	2.477	2.476	0.285
	0.544	0.3672	2.363	20.6	....	0.1464	....	2.475	....	......
8_0	0.781	1.1422	2.439	17.5	2.4396	....	....	....	....	......
	0.800	1.1422	2.438	18.0	....	....	....	....	....	......
8_1	0.766	1.0567	2.436	18.4	2.4372	0.0855	0.007	2.477	2.469	0.391
	0.783	1.0567	2.436	18.6	....	0.0855	....	2.461	....	......
8_2	0.765	0.9739	2.432	18.7	2.4344	0.0828	0.010	2.477	2.471	0.382
	0.745	0.9739	2.434	18.6	....	0.0828	....	2.465	....	......
8_3	0.745	0.9024	2.431	18.5	2.4317	0.0715	0.008	2.455	2.469	0.373
	0.730	0.9024	2.430	19.0	....	0.0715	....	2.483	....	......
8_4	0.713	0.7741	2.421	19.3	2.4225	0.1283	0.016	2.489	2.489	0.361
	0.696	0.7741	2.421	19.8	....	0.1283	....	2.489	....	......
8_5	0.675	0.6567	2.412	20.2	2.4129	0.1174	0.019	2.479	2.478	0.343
	0.659	0.6567	2.412	20.2	....	0.1174	....	2.476	....	......
8_6	0.623	0.5459	2.403	19.7	2.4042	0.1108	0.018	2.454	2.457	0.324
	0.636	0.5460	2.402	20.2	....	0.1107	....	2.460	....	......
8_7	0.565	0.3901	2.373	20.4	2.3743	0.1558	0.036	2.485	2.483	0.297
	0.550	0.3901	2.373	20.5	....	0.1559	....	2.480	....	......
9_0	0.761	1.0518	2.4377	17.6	2.4390	....	....	....	....	......
	0.757	1.0517	2.438	17.8	....	....	....	....	....	......
9_1	0.746	0.9638	2.436	18.5	2.4370	0.0880	0.007	2.455	2.460	0.375
	0.742	0.9638	2.436	18.6	....	0.0879	....	2.465	....	......
9_2	0.720	0.8689	2.432	18.8	2.4338	0.0949	0.010	2.475	2.467	0.366
	0.726	0.8689	2.433	18.5	....	0.0949	....	2.459	....	......
9_3	0.711	0.7981	2,429	18.6	2.4302	0.0708	0.008	2.466	2.475	0.357
	0.703	0.7981	2.429	18.8	....	0.0708	....	2.483	....	......
9_4	0.683	0.6932	2.423	19.5	2.4238	0.1049	0.016	2.473	2.474	0.345
	0.667	0.6931	2.422	19.6	....	0.1050	....	2.474	....	......
9_5	0.628	0.5846	2.415	20.2	2.4161	0.1086	0.019	2.469	2.466	0.327
	0.644	0.5845	2.415	20.2	....	0.1086	....	2.463	....	......
9_6	0.613	0.4867	2.406	19.8	2.4064	0.0979	0.018	2.458	2.465	0.308
	0.585	0.4866	2.404	20.2	....	0.0979	....	2.473	....	......
9_7	0.548	0.3471	2.375	20.5	2.3765	0.1396	0.031	2.488	2.484	0.283
	0.524	0.3471	2.375	20.5	....	0.1395	....	2.481	....	......

The following densities were found for glass very slowly cooled from fusion:

No.	7_7	8_7	9_7
M	0.3102	0.3424	0.2779
Δ_0	2.495	2.498	2.501

Table VIII, constructed on the plan described for Tables VI and VII, contains results for the variation of density along the transverse axis of drops annealed in boiling sulphur at 450°. Polariscopic observation showed these drops to be free from strain.

TABLE VIII.—*Structure of Prince Rupert drops annealed at* 450°.

No.	Diameter.	M	Δ_t	t	Mean Δ_0	μ	ϑ	δ	Mean δ	R
	cm.	*grm.*		°C.		*grm.*	*cm.*			*cm.*
1_0	0.766	1.1663	2.439	19.0	2.4398					
	0.768	1.1662	2.439	19.0						
1_1	0.708	0.8897	2.424	17.0	2.4242	0.2766	0.028	2.489	2.491	0.369
	0.713	0.8897	2.423	17.4		0.2765		2.493		
1_2	0.685	0.7859	2.414	17.4	2.4147	0.1038	0.011	2.503	2.503	0.350
	0.690									
2_0	0.980	1.8913	2.441	19.0	2.4420					
	0.884	1.8914	2.441	19.2						
2_1	0.920	1.4791	2.429	17.4	2.4303	0.4122	0.029	2.488	2.484	0.451
	0.828	1.4790	2.430	17.4		0.4124		2.481		
2_2	0.798	1.3118	2.422	17.4	2.4231	0.1673	0.021	2.484	2.484	0.426
	0.866									
6_0	0.792	1.2048	2.446	19.0	2.4468					
	0.797	1.2048	2.446	19.0						
6_1	0.743	0.9329	2.434	17.2	2.4350	0.2719	0.027	2.487	2.488	0.384
	0.738	0.9329	2.434	17.4		0.2719		2.490		
6_2	0.707	0.8436	2.4274	17.4	2.4284	0.0893	0.015	2.504	2.504	0.362
	0.712									

In Table IX, finally, we give the results for the Prince Rupert drops Nos. 10 and 11. The first two shells were removed from the drops while in the original (quenched) state. Both were then annealed for two hours at 450° and a further removal of shell effected. The numbers referring to the annealed state are primed. In other respects the notation is that of the preceding tables.

TABLE IX.—*Structure of Prince Rupert drops.*

No.	Diameter.	M	Δ_t	t	Mean Δ_0	μ	ϑ	δ	R	Remarks.
	cm.	*g.*		°C.		*g.*	*cm.*		*cm.*	
10_0		1.2984	2.4333	21.5	2.4346					Quenched.
		1.2985	2.4331	21.9						
10_1	0.775	1.0766	2.4260	22.0	2.4269	0.2218	(0.02)	2.471	(0.39)	
	0.747	1.0767	2.4250	22.2		0.2248		2.475		
10_2	0.735	0.9014	2.4147	21.3	2.4166	0.1732	0.022	2.487	0.370	
	0.699	0.9014	2.4160	21.5		0.1733		2.475		
$10'_2$	0.733	0.9014	2.4253	22.0	2.4263					Annealed at 450°, 2h.
	0.700	0.9014	2.4246	22.2						
$10'_3$	0.697	0.7425	2.4127	22.0	2.4136	0.1589	0.020	2.488	0.348	
	0.654	0.7425	2.4118	22.3		0.1589		2.488		
$10'_4$	0.656	0.6133	2.3958	22.4	2.3982	0.1292	0.020	2.498	0.328	
	0.617	0.6132	2.3978	21.5		0.1293		2.482		

TABLE IX.—*Structure of Prince Rupert drops.*—Continued.

No.	Diameter.	M	Δ_t	t	Mean Δ_0	μ	ϑ	δ	R	Remarks.
	cm.	*g.*		°*C.*		*g.*	*cm.*		*cm.*	
11_0	....	1.0470	2.4350	21.6	2.4357	....	....	....	....	Quenched.
	....	1.0457	2.4337	21.7	....	....	....	....	....	
11_1	0.730	0.8555	2.4271	22.0	2.4281	0.1915	(0.02)	2.473	(0.37)	
	0.707	0.8555	2.4263	22.2	....	0.1902	....	2.469	....	
11_2	0.690	0.7173	2.4138	21.5	2.4147	0.1382	0.020	2.500	0.350	
	0.670	0.7173	2.4131	21.6	....	0.1382	....	2.499	....	
$11'_2$	0.690	0.7172	2.4245	22.0	2.4261	....	....	....	....	Annealed at 450°, 2h.
	0.670	0.7173	2.4249	22.0	....	....	....	....	....	
$11'_3$	0.626	0.5825	2.4077	22.1	2.4086	0.1347	0.023	2.502	0.329	
	0.644	0.5825	2.4067	22.2	....	0.1348	....	2.508	....	
$11'_4$	0.603	0.4678	2.3894	22.5	2.3919	0.1147	0.023	2.487	0.306	
	0.578	0.4677	2.3917	21.6	....	0.1148	....	2.471	....	

Discussion.—An inspection of Tables VI and VII shows at once that Δ_0, the density of consecutive cores, continually decreases. This is easily accounted for, since the bubble error becomes relatively large as the mass (M) of the Prince Rupert drop decreases.

If we construct the density of consecutive shells (δ) as a function of their mean radius (R) and then compare the diagrams which obtain for the five Prince Rupert drops, Nos. 3, 5, 7, 8, 9, we find that the loci have no salient feature in common. Possibly an increase of δ as we approach the deeper layers may be discernible, but it is indistinct. Hence the true variation of δ from surface to axis of a Prince Rupert drop is here unrecognizably obscured by errors of observation. Indeed, we shall find below that the probable total variation of δ attributable to strain will not far exceed 0.5 per cent. The accuracy of δ is certainly not within this figure. Again, if we compare the contours of corresponding curves $\delta = f(R)$, in Table V for drops free from strain, with each other and with the contours belonging to Tables III and IV, we encounter fluctuations of the same kind in both cases. These errors include the inaccuracies of mere measurement (the mass of the drops is unfortunately small and the pycnometer methods are not easily applicable), as well as such discrepancies as result from the unavoidable invasion of small bubbles during solution.

If, however, we compare the *mean* values of δ for strained shells (Tables VI, VII, and IX) with the mean values of δ for shells free from strain (Tables VII and IX), we find the latter values (unstrained glass) always in excess of the former. In other words, although our results are insufficiently sharp to enable us to describe the exact nature of the temper strain in glass, they do permit us to classify it as a *strain of dilatation*, so far as we have observed, throughout the substance of the drop. This observation is of importance, and we have therefore drawn up the following general tabular comparison, to supplement the special and direct comparison given in Table IX.

In Table X Δ_s is the density of the glass itself after thorough annealing at red heat, as found in our earlier section, page 117, the datum being the mean value for six drops; Δ'_s is the density of the glass after *fusion* in a platinum basket and very slow cooling. The additional increment of the density of the glass thus produced is to be noted. δ_h and δ' denote the densities of shells strained (quenched) and unstrained (annealed at 450°), respectively. The sixth column contains the relative value of decrement of density for each drop; the second column, finally, the number of shells whose average δ is the datum given.

TABLE X.—*Density relations of tempered glass relative to soft glass (mean results for shells).*

$\Delta_s = 2.491$			$-\frac{\delta' - \Delta_s}{\Delta_s} = 0$		
Prince Rupert drop No. —	Number of shells dissolved.	δ_h		Δ'_s	$-\frac{\delta_h - \delta'}{\Delta_s}$
3	3	2.473 ± 0.006	....	....	0.0076
5	3	2.479 ± 0.008	....	....	0.0052
7	7	2.477 ± 0.003	....	2.495	0.0060
8	7	2.474 ± 0.004	....	2.498	0.0072
9	7	2.470 ± 0.003	....	2.501	0.0088
10	2+2	2.477 ± 0.008	2.489 ± 0.002	....	0.0064
11*a*	2+2	2.485 ± 0.029	2.492 ± 0.026	....	0.0028
1	2	....	2.497 ± 0.006	....	....
2	2	....	2.484 ± 0.000	....	....
6	2	....	2.496 ± 0.008	....	....
Mean	($\frac{41}{10}$)	2.476	2.492	2.498	0.0063

a In view of the large value of probable mean error of this measurement, we thought seriously of rejecting it; but we were unable to find any error in the work, and hence the datum has been retained. Its effect is principally apparent in the ratio, which it depresses in a way adverse to our inferences.

To facilitate further comparison, we insert also the corresponding table for steel.[1] Here 2ρ are the diameters of the steel rods; Δ_h, Δ_s, Δ_c, their densities in the hard, the soft, and the commercial soft states, respectively. Δ', finally, denotes the observed densities of steel at the end of the first phase of annealing (350°), and therefore applies for rods free from æolotropic strain. The table gives us the following relative decrements of density: column first, the total decrement; columns second and third, the decrements corresponding to the first and second phases of annealing, respectively.

[1] See Bull. No. 27, U. S. Geol. Surv., p. 46.

TABLE XI.—*Density variations of tempered steel relative to soft steel.*

No.	2ρ	$-\frac{\Delta_h-\Delta_s}{\Delta_c}$	$-\frac{\Delta_h-\Delta'}{\Delta_c}$	$-\frac{\Delta'-\Delta_s}{\Delta_c}$
I	1.90	0.0048	0.0018	0.0029
II	0.58	0.0155	0.0060	0.0095
61 to 63....	0.13	0.0171	0.0068	0.0103
0..........	0.23	0.0133	0.0080	0.0053
21 to 29....	0.08	0.0150	0.0033	0.0116
Mean ...	......	0.0131	0.0052	0.0079

Tables X and XI show that both in the case of glass and of steel the mean strain effect of sudden cooling is *dilatation* throughout the mass of the quenched material,[1] that the mean amounts of dilatation for glass and for steel are of like order, and that the strain in glass exceeds that of steel. We find, in general, that the practically measurable value of density is not a satisfactorily sharp datum for discerning the primary causes of the electrical, the optic, and the magnetic variations of the substance quenched. These, therefore, will have to furnish nice descriptions of strain and interpret what we have called elsewhere the individuality of magnets.

In the above paragraphs we have pursued the analogy between the optical behavior of tempered glass and the electrical behavior of tempered steel into every detail of consideration which urged itself. We availed ourselves, moreover, of additional criteria given by the density relations of the whole or of similar parts of the bodies quenched. At every stage of our work we reached data alike in character both for steel and for glass. With these results we are further justified in maintaining that sudden cooling of steel is accompanied by a strain effect of a distinct and individual kind and of an intensity sufficient to account for the electrical properties of steel (thermo-electric and resistance constants) such as we have found them.

In one of the earlier paragraphs of the present paper we pointed out that in its divers relations to hardness steel is distinguished from glass. To further our investigation it will therefore next be necessary to inquire more specifically into the causes of hardness itself, and at the same time to endeavor to throw light on the mysterious transformations of carbon.

§ III. THE HYDRO-ELECTRIC EFFECT OF TEMPER.

Our original object in writing these papers was that of elucidating questions having reference to the carburation of steel, from a purely physical standpoint. The reasoning available to the physicist is, however, of an analogical kind, and therefore as dangerous as it is fascinating. Hence, in view of the time already spent, it seemed expedient to en-

[1] If "quenching" means sudden cooling, then if the solid quenched be massive and thick the deep layers cannot be quenched in virtue of their position.

deavor to cut more nearly down into the heart of the inquiry and to determine directly the carbon relations of steel as a function of the temperature (0° to 400°, 400° to 1000°) and of the time of annealing and to do this with full reference to the physical occurrences observed in the first and second phases of the phenomenon. So far as we know, M. Caron[1] alone has occupied himself with similar work; but his researches, being largely restricted to the extreme states "hard" and "soft," are incomplete. The carburation effect of annealing at measured temperatures during stated times is quite unknown.

Glass hard steel rods about 0.1^{cm} in diameter and tempered uniformly in the way described elsewhere[2] were each broken into four nearly equal parts and four samples of hard steel identical in composition and temper were thus obtained. These samples were annealed at 20° (glass hard), 100° 4^h, 200° 1^h, 360° 1^h, 1000° 5^m, respectively. Having treated these with cold dilute hydrochloric acid, we found that the rods annealed at 20° and at 100° dissolved without perceptible residue to a clear liquid; those annealed at 200° left a trace of flocculent carbon. Rods annealed at 360° yielded flocculent carbon in considerable amount; rods annealed at 1000°, finally, a comparatively copious and heavy carbon precipitate. The residues were collected in a weighed Gooch crucible (asbestus filter), thoroughly washed in the usual way,[3] dried, weighed, ignited in oxygen, again weighed, and the loss of weight on ignition estimated as carbon. The results thus obtained are sufficient for the present purposes:

Annealed at	20°, ∞	100°, 4^h	200°, 1^h	360°, 1^h	1000°, 5^m
Uncombined (graphitic) carbon per gramme steel, c.	<0.0007	<0.0007	0.0009	0.0021	0.0047

In a second series of similar experiments we found—

Annealed at	20°, ∞	100°, 10^h	200°, 1^h	360°, 1^h	450°, 1^h	1000°, 30^m	Commercial (soft).
Uncombined (graphitic) carbon per gramme steel, c.	0.0001	0.0005	0.0005	0.0014	0.0009	0.0033	0.0053

In general, c increases at an accelerated rate with temperature. The large datum for the commercial state, as compared with the smaller values of c for steel softened by mere heating to redness, is an interesting feature of these results. The importance of the time effect is also to be noted. Temperatures as low as 100°, when acting on hard steel for long intervals of time (10^h), produce perceptible precipitation of the carbon in steel.

[1] Caron: Comptes-rend., LVI, pp. 43, 211, 325, 1863.

[2] Bull. 14, U. S. Geol. Surv., p. 29, 1885; Bull. 27, U. S. Geol. Surv., p. 30, 1886.

[3] Using dilute HCl, hot water, solution KOH, alcohol, and ether. See Blair: Report of the Board on Testing Iron, &c., I, p. 248. Washington, 1881.

On closer inspection it appeared that steel annealed at 100° is, cæteris paribus, more easily soluble than glass hard steel; steel annealed at 200° more easily soluble than steel annealed at 100°, and steel annealed at 360° more easily soluble than steel annealed at 200°. In other words, the rate at which solution takes place in general increases as temper continually decreases. These curious results were substantiated by annealing one-half of short glass hard rods (ca. 5^{cm} in length) at red heat on dissolving in HCl, the diameter of the soft length is diminished more rapidly than the diameter of the hard length. The diminution is usually greatest near the middle of the rod, where hard and soft parts meet, showing probably that local galvanic action here produces a perceptible result. At the same time steel annealed for hardness at a temperature in low redness is probably more soluble than steel in any other state of temper, hard or soft. Examples are given in the next table.

If we define the rate of solution as the mass dissolved per unit of area per unit of time, then in case of two submerged cylinders, for which during the time t the radii are reduced from ρ_0 to ρ and from ρ_0 to ρ', respectively, the rates, cæteris paribus, will be to each other as corresponding values of the expression—

$$-\delta\int_{\rho_0}^{\rho}\frac{2\pi\rho d\rho}{2\pi\rho}, \text{ or as } \frac{\rho_0-\rho}{\rho_0-\rho'}$$

The following table contains some of the results obtained with rods in the hard (h) and the soft (s) states, respectively, dissolved in acid, HCl, under identical conditions. m refers to the middle parts of the rods, concerning which mention has already been made. These ratios are subject, of course, to large variations (1 to 20), depending on the method of annealing, &c. The table is a fair exhibit of average values. The rods are lettered A, B, C, D.

TABLE XII.—*Rates of solution of hard and soft steel.*

[Original diameter, $2\rho_0 = 0.120^{cm}$.]

	Diameter.				Rates.				
	A.	B.	C.	D.	A.	B.	C.	D.	Mean rate.
h	0.111	0.111	0.110	0.110	1.0	1.0	1.0	1.0	1.0
m	0.101	0.100	0.098	0.100	1.7	1.7	1.8	1.6	1.7
s	0.102	0.103	0.102	0.103	1.6	1.5	1.5	1.4	1.5
h	0.101	0.100	0.100	0.099	1.0	1.0	1.0	1.0	1.0
m	0.080	0.084	0.083	0.081	1.7	1.6	1.6	1.7	1.6
s	0.094	0.092	0.091	0.090	1.3	1.3	1.3	1.3	1.3
h	0.069	0.071	0.073	0.072	1.0	1.0	1.0	1.0	1.0
m	0.045	0.045	0.043	0.044	1.4	1.5	1.6	1.5	1.5
s	0.067	0.070	0.070	0.071	1.0	1.0	1.0	1.0	1.0

TABLE XII.—*Rates of solution of hard and soft steel*—Continued.

[Original diameter, $2\rho_0 = 0.126^{cm}$.]

	Diameter.				Rates.				
	A.	B.	C.	D.	A.	B.	C.	D.	Mean rate.
h	0.122	0.123	0.122	0.122	1.0	1.0	1.0	1.0	1.0
s	0.115	0.116	0.115	0.113	2.7	3.3	2.8	3.2	3.0
h	0.116	0.116	0.116	0.115	1.0	1.0	1.0	1.0	1.0
s	0.103	0.108	0.106	0.104	2.3	1.8	2.0	2.0	2.0
h	0.090	0.090	0.089	0.090	1.0	1.0	1.0	1.0	1.0
s	0.052	0.061	0.052	0.058	2.0	1.8	2.0	1.9	1.9
h	0.078	0.077	0.077	0.076	1.0	1.0	1.0	1.0	1.0
s	0.038	0.029	0.028	0.042	1.8	2.0	2.0	1.7	1.9
[Original diameter, $2\rho_0 = 0.082^{cm}$.]									
h	0.077	0.077	0.078	0.076	1.0	1.0	1.0	1.0	1.0
s	0.070	0.065	0.066	0.068	2.4	3.4	4.0	2.3	3.0
h	0.070	0.070	0.070	0.070	1.0	1.0	1.0	1.0	1.0
s	0.060	0.051	0.059	0.051	1.8	2.6	1.9	2.6	2.2
h	0.043	0.041	0.044	0.043	1.0	1.0	1.0	1.0	1.0
s	0.000	0.000	0.000	0.000	2.1	2.0	2.1	2.1	2.1

From these results we inferred that hard and tempered steel would probably be distinguishable hydro-electrically; that, for the first phase of the phenomena of annealing, at least, this distinction might be more delicate than the estimation of precipitated carbon. To test this inference we selected the rods Nos. 1 to 12, quenched uniformly glass hard by our method. These were then broken in the middle and the first half of each rod was left in the glass hard state. The other halves were annealed in pairs at 20°, 100°, 4^h, 185°, 360°, 450°, 1000°, respectively. In order to anneal these (long) rods uniformly, we used a special device by which they were drawn vertically upward through a zone of constant temperature by clock work. If h be the height of this zone and ρ the radius of the disk or drum revolving once an hour, then

$$t = \frac{h}{2\pi\rho}$$

is the time of annealing in hours. Again, if we make $h = 2\pi$, then the time of exposure in hours is the reciprocal of the radius of the disk in centimeters. The great advantage of this method of annealing is that it requires but a very *small* zone of constant temperature;[1] it is therefore applicable at all temperatures and almost invaluable for high temperature work (500° to 1500°), where zones of a definite constant temperature are not easily produced. In this way we obtained six *pairs* of hydro-electric couples, each of which consisted of glass hard steel and the same steel annealed at one of the temperatures specified. Our first results were investigated with a zero method, and showed clearly that

[1] $2\pi \times \pi\,(0.3)\,\overline{\text{cm}}^{\,3}$ or even a narrower cylindrical figure being sufficient.

annealed steel is hydro-electrically positive with reference to hard steel and that the electromotive force increases with the difference of temper. But in view of the large polarization discrepancies incident to these measurements, the electrometer is preferable to the zero instrument. The following results were obtained with Mascart's apparatus adjusted to indicate 0.001 volt accurately. The electrodes of the steel couple were immersed in a concentrated solution of pure zinc sulphate contained in a U tube, the two limbs of the tube receiving the two steel wires. We kept them scrupulously bright by repeated scouring with sand paper. In the tables we give the electromotive forces, e, of the divers couples of hard and tempered steel, as well as the probable mean error, δe, of each. The means of the two values of e for each temperature of annealing are given in the second horizontal row and fairly exhibit the hydro-electric effect of temper in question.

The following data are the mean results of four sets of measurements of five observations per set. The rods were scoured before beginning the first and the third of these sets.

	No.	$e \times 10^3$	$\delta e \times 10^3$	Mean $e \times 10^3$
Annealed at 20°	9	± 4	....	±0.009
	10	±13	....	
Annealed at 100°	1	+12	±4	+0.000
	2	− 2	±5	
Annealed at 190°	3	+19	±3	+0.020
	4	+20	±1	
Annealed at 360°	5	+36	±3	+0.035
	6	+34	±3	
Annealed at 450°	7	+35	±3	+0.037
	8	+40	±3	
Annealed at 1000°	11	+49	±4	+0.052
	12	+54	±4	

The following data are the mean results of four sets of five observations per set; rods scoured before commencing each set of measurements:

	No.	$e \times 10^3$	$\delta e \times 10^3$	Mean $e \times 10^3$
Annealed at 20°	9	± 5	....	±0.003
	10	± 2	....	
Annealed at 100°	1	+ 8	±3	+0.007
	2	+ 7	±1	
Annealed at 190°	3	+20	±3	+0.022
	4	+24	±2	
Annealed at 360°	5	+34	±5	+0.030
	6	+27	±1	
Annealed at 450°	7	+35	±2	+0.039
	8	+43	±2	
Annealed at 1000°	11	+51	±2	+0.058
	12	+65	±5	

The following data, finally, are the mean results of two sets of three observations per set; rods scoured before commencing each set of measurements:

	No.	$e \times 10^3$	$\delta e \times 10^3$	Mean $e \times 10^3$
Annealed at 20°	9	± 2	....	±0.003
	10	± 4	....	
Annealed at 100°	1	+ 6	±2	+0.006
	2	+ 6	±1	
Annealed at 190°	3	+16	±3	+0.021
	4	+25	±1	
Annealed at 360°	5	+36	±2	+0.035
	6	+34	±1	
Annealed at 450°	7	+37	±2	+0.038
	8	+39	±2	
Annealed at 1,000°	11	+59	±6	+0.062
	12	+65	±8	

The electromotive forces here encountered are small. It is necessary to take extreme precautions against all sources of error; otherwise mere discrepancies of polarization will exceed the largest values of electromotive force (e) found. If the parts of the liquid in which the steel wires are immersed differ at all in composition we may look for a difference of potential at the surface of separation of those parts. The number of such surfaces in a solution of solid liquid or gas may be indefinite. Hence it appeared desirable to repeat the above experiments with distilled water in place of zinc sulphate, to exchange the limbs of the U tube twice for each series of measurements (commutation), and to submerge equal surfaces of steel electrode in all cases. The results follow:

	No.	$e \times 10^3$	$\delta e \times 10^3$.	Mean $e \times 10^3$
Annealed at 0°	9	± 18	....	±0.023
	10	± 28	....	
Annealed at 100°	1	+ 12	± 5	+0.020
	2	+ 28	± 9	
Annealed at 190°	3	+ 33	± 7	+0.027
	4	+ 20	± 8	
Annealed at 360°	5	+ 93	±11	+0.089
	6	+ 85	± 6	
Annealed at 450°	7	+128	±15	+0.105
	8	+ 82	± 9	
Annealed at 1000°	11	+166	± 5	+0.185
	12	+205	± 3	

A few supplementary data are contained in the next table, where Nos. I and II are (+) iron /(−) steel couples, both metals in the soft state; No. III, a couple of nominally identical iron wires; Nos. IV and V, couples consisting of steel in the commercial, drawn state (+), and the same steel softened by heating to redness (—). The couples are immersed in water.

I.	II.	III.	IV.	V.
$e\times10^3$	$e\times10^3$	$e\times10^3$	$e\times10^3$	$e\times10^3$
$+26\pm3$	$+63\pm2$	±20	-69 ± 5	-65 ± 12

The general results of these measurements are in accordance; the variations of potential, when taken as a whole, regular and decided. They show that *as hardness increases the hydro-electric position of steel moves continually in an electro-negative direction.* The electromotive forces encountered are larger for the electrolyte distilled water than for zinc sulphate. The total range of variation in the former case (water) may exceed 0.25 volt. For zinc sulphate it scarcely reaches one-third of this amount and decreases as the time of immersion increases. After the first immersion, moreover, the original electromotive force is not fully restored even by rubbing the electrodes.[1] When steel is immersed in water the effect of repeated scouring seemed to be an increase of electromotive force. But these and like annoyances, which make the study of polarization phenomena unsatisfactory, are too well known to need further comment here.

If we avail ourselves of the observations made above on the rate of solution of tempered steel, we may infer consistently with all the facts adduced that, since the tempered electrode is covered with hydrogen[2] at a greater rate than the hard electrode, the former must be positive with respect to the other; that the phenomena in hand are mere effects of polarization. In other words it is permissible to assume that the continuous variation of mechanical texture producible by annealing is the cause of corresponding variations of the rate at which hydrogen is deposited on the submerged metal; that the electromotive forces observed are expressions of this hydrogen polarization and bear no immediate relation to the electro-chemical character of the steel electrode.

On the other hand the dependence of the hydro-electric position of steel, cæteris paribus, on the amount of free carbon contained is sufficiently obvious to conflict with this view. To facilitate comparison we insert the following table. Here c denotes the number of grammes of free carbon per gramme of steel; e and e' show the difference of potential between steel tempered and steel hard when plunged in zinc sulphate and in water, respectively; $\varDelta$ is the density, s the specific resistance, α the

[1]After long exposure of the wires to air the original electro motive force again appears.

[2]Hydrogen accumulates visibly on the + electrode when both are immersed in zinc sulphate.

resistance temperature coefficient, h the thermo-electric hardness of wires of the same kind of steel. α and h are obtained by calculation.

TABLE XIII.

[Diameter, $2\rho=0.081$.]

Annealed from hard at—	c	e	Δ	s	α	h	e'
° 20 ∞	0.0001	0.000	7.6547	43.9	0.0017	18.1	0.000
100, 1^h	....	....	7.6666	39.3	0.0018	16.2	....
100, 13^h	0.0005	0.006	7.6745	35.5	0.0020	14.6	0.020
190, 4^h	....	....	7.6841	30.8	0.0023	12.7	....
190, 4^h, 30^m	....	....	7.6808	27.1	0.0027	11.2	....
Do	0.0007	0.020	7.6848	27.1	0.0027	11.2	0.027
350	0.0017	0.033	7.6806	20.7	0.0033	8.5	0.089
450, 1^h	0.0009	0.038	7.7190	18.4	0.0036	7.6	0.105
530	....	....	7.7227	18.2	0.0036	7.5	....
690	....	....	7.7272	17.2	0.0038	7.1	....
810	....	....	7.7586	17.6	0.0037	....	....
1,000	0.0040	0.057	7.7705	18.6	0.0037	....	0.185
Commercial	0.0053	....	7.7268	16.3	0.0039	6.7	0.252

When steel of a given kind is operated upon, and total carbon therefore a fixed quantity, the variable c affords a comparatively convenient means for detecting the presence and amount of chemical change; but it is highly probable that a much clearer insight into the nature of the decomposition of carbide produced by annealing hard steel would be obtainable from a study of the character and quantity of the hydrocarbons[1] (gaseous liquid) volatilized during solution. They accumulate in copious amounts long before the precipitation of carbon is perceptible, or even when no appreciable precipitation occurs. If we regard c and e or e' correlated, then we have in hand an example of an exceedingly remarkable decomposition, which may be regarded as incipient in hard steel even at ordinary temperatures, which is a certainly perceptible occurrence after annealing at only 100°, and which becomes more and more definitely marked and distinct as the temperature and time of annealing increase. The anomalous character of this species of decomposition, when occurring in a rigid solid, we have already fully pointed out. To obtain further information it is essential that the variable c be investigated minutely. We remark that the critical difference between the thermo-electric (h) and the hydro-electric (e) behavior of steel is well shown by constructing h as a function of e'. This is done in figure 10, which also contains c in its relations to e'.

[1] The liquid and volatile constituents seem to increase in amount as the steel dissolved is harder.

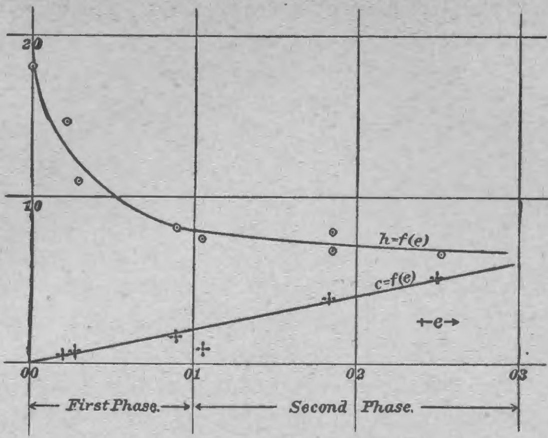


FIG. 10. Diagram illustrating the relation of graphitic carbon and thermo-electric hardness to the hydro-electric position of steel.

RETROSPECTIVE REMARKS.

The present results have materially substantiated our earlier views at every essential point. We may, nevertheless, further point out the presence and the importance of the strain effect by the following simple considerations:

The mass constants of the three types of cast iron, the extreme gray, the intermediate mottled, and the extreme white, range between the maximum density of 7.6 for white cast iron and the minimum density of 6.9 for gray cast iron. Density, therefore, *increases* in marked degree in proportion as total carbon is more and more nearly combined (from "gray" to "white"). Quite the reverse of this is true for steel, where density decidedly *decreases* as total carbon is more and more nearly combined (from soft to hard). This discrepancy is the temper strain, a strain of dilatation, which, in Chapters I and II, we carefully compare with the analogous behavior of glass. It is to be remembered that the given differences of density apply even to parts of the *same* cast of iron,[1] when these parts are respectively cooled rapidly (white) or slowly (gray).

With these general indications of the occurrence of stress, it is an important desideratum to obtain some estimate of its value. One method premises that the work done in mechanically expanding steel or glass from normal density to quenched density is equivalent to the work done by heat in effecting the same expansion. Here we have

$$\int p\, dv = A\, c\, T$$

where in one case unit of mass is acted on by a force p dynes per square centimeter during the volume increase dv cubic centimeters; where, in the other case, an identical total volume increment $(\int dv)$ is produced

[1] Karsten: Eisenhüttenkunde, Bd. I, 3. Aufl., p. 581 ff, 1841.

by an excess of temperature T degrees centigrade, applied to the same unit of mass and of mean specific heat c. A is Joule's equivalent. If, instead of variable p, we employ a mean constant value, P, and put for T the thermal value $\frac{1}{3\alpha}\int dv$,

We find

$$P=A\,\frac{c}{3\alpha}$$

Here

$$A=42\times 10^{6},\ c=0.2,\ 3\alpha=25\times 10^{-6}$$

hence we obtain

$$P=320\times 10^{9}$$

dynes per square centimeter, or circa 300,000 atmospheres. This is an absurdly large value and shows that in case of thermal expansion internal work is done which is not registered in mere volume increase.

We obtain very plausible stress values by introducing the elastic properties of glass or steel, probably because we are here relatively free from hypotheses. The compression (negative expansion) produced by quenching glass or steel is given in Tables X and XI, § II, and may be accepted as 5×10^{-3}. The volume resilience of glass and of steel, according to Professor Everett's[1] measurements, is 4×10^{11} and 2×10^{12}, respectively. Hence, if the force resisted in producing the volume increment of quenching be equivalent to the force producing the identical compression, we find $P=10\times 10^{9}$ dynes per square centimeter for steel and $P=2\times 10^{9}$ for glass. Now, the tenacity of steel is 8×10^{9} per square centimeter; the tenacity of glass, 0.6×10^{9} per square centimeter. The ratio of stress to tenacity is therefore 1.3 for steel and 3.3 for glass. This shows that in both cases stress and tenacity are of the same order, and that stress is in excess, and but for the peculiarly favorable and resisting arched structure of the quenched globule would give rise to rupture — in glass certainly, very probably also in steel. These results are estimates and are in accord with the observed explosive property of the Prince Rupert drop, and with the less pronounced tendency of steel to crack on quenching. We may infer, therefore, that quenched glass and quenched steel are under mean stress intensities of several thousand atmospheres; and in discussing the corresponding viscous properties of these substances they must be brought into relation with these high intensities of peculiar stress.

We call attention, in concluding, to the deductions of our earlier paper: "The annealing of steel, considered physically, is at once referable to the category of viscous phenomena. In the ordinary cases of viscosity measurements the phenomenon is evoked by sudden application of stress (torsion, flexure, tension, volume compression, &c.) under conditions of constant viscosity; in the case of annealing, by sudden de-

[1] Everett: Phil. Trans., p. 369, 1867. The above are round numbers.

crease of viscosity under conditions of initially constant stress. Thermal expansion interferes with the purity of these phenomena by destroying the conditions of existence of the strain which accompanies hardness, and this in proportion as the expansion is greater."[1]

Again, irrespective of the manifestation of mere hardness: "The existence of the characteristic strain in glass hard steel is the cause of electrical effects so enormous that such additional effects which any change of carburation may involve may be disregarded, and all electrical and magnetic results interpreted as due to variations in the intensity of the said strain."[2]

This deduction applies of course to the first phase of the phenomena of annealing, since it is within these limits that the strain in question is brought to vanish. With these results in hand we may proceed justifiably toward a study of the question whether the conditions for the permanent retention of magnetism in an iron carburet are not the identical conditions for the permanent retention of any strain. If we select the temper strain for comparison, we do it not merely because long experience has familiarized us with this strain, but because of the clear cut beauty of its manifestations and because of the simplicity of the functions which describe it.

WASHINGTON, *September*, 1886.

---

[1] Bull. 14, U. S. Geol. Surv., p. 196. [2] Id., p. 197.

THE SPECIFIC GRAVITY OF LAMPBLACK.

BY WILLIAM HALLOCK.

The six samples of lampblack which formed the subject of this investigation were kindly furnished by Mr. Samuel Cabot, manufacturer of lampblack, in Boston, as samples of the different grades of commercial lampblack made by him. With the six samples came the following specifications with regard to the source or method of the manufacture of each:

I. Black from kerosene.
II. Black from coal tar naphtha.
III. Black from natural gas.
IV. Black from dead oil.[1]
V. Black from dead oil; very hot.[2]
VI. Black from dead oil; very light and fine.[3]

In order to get more nearly the pure lampblack, free from oil, &c., in each case, all the samples were washed in benzol, alcohol, and boiling water and dried at 180° C.

The following table will show the effects of the above washings; also, the percentage of ash, the original weight of the substance after standing fifteen hours in a desiccator being 100 per cent.

Number of sample.	I.	II.	III.	IV.	V.	VI.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Dried at 180° C	98.5	99.0				
Washed with alcohol and dried at 180° C	97.0	98.0	99.4	96.9	98.2	98.5
Washed with water at 100° and dried at 180° C	96.9	....	....	....	....	....
Washed with benzol and dried at 180° C.	96.9	....	....	....	....	....
Ignited in O. ash	0.08	0.3	0.45	0.08	0.2	0.02

[1] This sample is from the back part of the receiving house, where small furnaces are used, and therefore the black is not highly heated.

[2] This sample is from houses where the furnaces are very large; therefore the black is exposed to a high degree of heat. It gives a large yield and is a cheap black.

[3] This sample is fine black from near the furnaces in the same receivers as IV.

The portions used for the determinations were washed in benzol, alcohol, and boiling water, dried at 180° C., and weighed after being in the balance case long enough to have a constant weight; of this point the particulars will be given later.

The specific gravity was determined by the pycnometer, using 10 per cent. alcohol as the liquid. The specific gravity of this was found to be 0.9864 at 20°.0C. In each case the sample was weighed dry in the pycnometer, then covered with 10 per cent. alcohol and put under the receiver of an air pump for several hours, until air was no longer given off. A test determination demonstrated that this did not appreciably alter the specific gravity of the liquid. After that the vessel was carefully filled, so as not to stir up the carbon settled on the bottom, the stopper put in, and the whole was weighed; then the stopper was removed and a small delicate thermometer was inserted into the liquid and the temperature noted. The pycnometer was then again closed, weighed, &c. Thus there were obtained three readings of the temperature and three weighings, the mean of which in each case served to calculate the specific gravity.

In this way the following values were found:

	1.7231			1.7668	
No. I.	1.7233	1.723	No. IV.	1.7665	1.767
	1.7227			1.7670	
	1.7797			1.7890	
No. II.	1.7797	1.780	No. V.	1.7887	1.789
	1.7803			1.7881	
	1.7513			1.7637	
No. III.	1.7521	1.752	No. VI.	1.7636	1.764
	1.7521			1.7641	

Too much reliance must not be placed upon these values, owing to the fact that the lampblack condenses on its surface a large amount of air, which is weighed with it when the weighing in air is made, but is absent when it is covered with the liquid. An idea of the extent to which this may affect the determinations may be obtained from the following statement.

A sample of No. II was taken after the washings and dryings, similar to that used for the specific gravity. The original weight is called 100 per cent:

Heated 2^h to 180°, then 24^h in H_2SO_4 desiccator	*a*	98.8
Heated 1^h to 180°, then 2^h in H_2SO_4 desiccator	*b*	98.7
5^h in balance case	*c*	100.55
Heated 3^h to 180°, then 40^m in H_2SO_4 desiccator	*d*	98.76
2 months in H_2SO_4 desiccator	*e*	99.2

Thus it appears probable the *dry carbon, free from air*, weighs only 98.75 per cent. (mean of *a*, *b*, *d*) of the weight as it comes from the sample tube and as used above for the specific gravity. This, if it is general, would lower the above values of the specific gravity by about 1.25 per cent., or 0.022.

An attempt was also made to obtain some idea of the size of the grains of the black by the rate of sedimentation, on the principle that the finer the particles the slower the sedimentation. For example, a *single* particle falls through a liquid with a velocity proportional to the square of its diameter (radius).

For this purpose 0.1 gr. of each sample was taken from that used for the determination of the specific gravity and placed in test tubes about 20^{mm} by 120^{mm} dimensions. Upon each was poured 3^{cc} of alcohol, then ten shot, 2^{mm} in diameter, were put in each tube to help break up the black. After vigorous shaking 5^{cc} of water was added; then the tubes were heated till the liquid boiled, placed under the receiver of an air pump, and the pressure was reduced till they boiled there, when they were left 18^{h} to remove any air which might be condensed on the surface of the carbon. The tubes were then filled with distilled water well shaken and stood up to sedimentate.

After standing for the time given in the ninth column, Table I, two-thirds of the liquid was poured into another tube and that placed aside. The original tube was then refilled with distilled water, well shaken, and stood up until the next decantation, and so on, until the contents of the original tube would settle in a day or less. Thus each sample was separated into a series of lots of different fineness. The time required by these decanted lots to settle is given in Table II.

Unfortunately these results cannot be expressed in a very clear way, but in general the following is true:

Sample I. Settles quite completely in fifteen minutes, and hence is coarse.

Sample II. Settles in one day, and is hence much finer than I and III; but not so fine as IV, V, or VI.

Sample III. Same as sample I.

Sample IV. A little finer and slower than No. II.

Sample V and VI. These two are very nearly alike and are both *much* finer than any of the rest. Sample VI is, however, decidedly the finer of the two.

Of course any sample may behave as if it were coarse when each grain is, in fact, an agglomeration of several. This is hardly likely in the the above samples, since, if such were the case, we would be apt to find some fine black even in samples I and III.

I am fully aware of the incomplete and primitive character of this investigation, and sincerely hope it may incite some one with plenty of time and energy to take up the subject thoroughly and either confirm or refute my conclusions.

TABLE I.

Number of decantation.	Time of decantation.	Sample I.	Sample II.	Sample III.	Sample IV.
1	May 28, 1886, 11.45 a. m.	Clear after 15 m.	Opaque	Clear after 15 m.	Opaque.
2	12.2 p. m	Discontinued	....do	Discontinued	Do.
3	2		Translucent		Do.
4	3. 25		....do		Dimly translucent.
5	3. 55		....do		Do.
6	May 29, 1886, 11 a. m.		Very translucent.		Medium translucent.
7	12. 30 p. m		Discontinued		Medium translucent; settles now in a few hours.

Number of decantation.	Time of decantation.	Sample V.	Sample VI.	Interval between decantations or shaking.	Total time since commenced.
1	May 28, 1886, 11.45 a. m.	Opaque	Opaque	1 h. 55 m	1 h. 55 m.
2	12. 2 p. m	....do	....do	17 m	2 h. 12 m.
3	2	....do	....do	1 h. 58 m	4 h. 10 m.
4	3. 25	....do	....do	1 h. 25 m	5 h. 35 m.
5	3. 55	....do	....do	30 m	6 h. 5 m.
6	May 29, 1886, 11 a. m.	Very weakly translucent.	....do	1 h. 30 m	7 h. 35 m.
7	12. 30 p. m	Very weakly translucent; settles now in a few hours.	Opaque; settles now in a day or so.	1 h. 30 m	9 h. 5 m.

TABLE II.

Decantation.	Sample I.	Sample II.	Sample III.	Sample IV.	Sample V.	Sample VI.
1	Less than 1 hour.	Less than 1 hour.	Less than 1 hour.	Less than 5 days.	Not in 20 days.	Not in 30 days.
2		....do		....do	Translucent in 5 days.	Do.
3		....do		....do	....do	Translucent in 20 days.
4				1 day	Clear in 5 days.	Translucent in 5 days.
5				Less than 1 hour.	Clear in 1 day.	Do.
6				....do	....do	Do.
7				....do	....do	Translucent in 1 day.

MISCELLANEOUS ANALYSES.

THE PERIDOTITE OF ELLIOTT COUNTY, KENTUCKY.[1]

[Specimens collected by J. S. Diller and analyzed by T. M. Chatard.]

A. Peridotite.
B. Olivine from peridotite.
C. Pyrope from peridotite.
D. Ilmenite from peridotite.
E. Syenite inclusion.
F. Slaty inclusion.
G. Calcareous sandstone near peridotite dike.
H. Indurated shale near peridotite dike.
I. Fine grained, fissile sandstone near dike.

	A.	B.	C.	D.
H_2O at 110°	8.92	.14	.17	.20
H_2O at red heat	......	.66		
CO_2	6.66	....	......	......
SiO_2	29.81	40.05	41.32	.76
TiO_2	2.20	.07	.16	49.32
P_2O_5	.35	.04	None	Trace
Cr_2O_3	.43	.24	.91	.74
Al_2O_3	2.01	.39	21.21	2.84
Fe_2O_3	5.16	2.36	4.21	9.13
FeO	4.35	7.14	7.93	27.81
MnO	.23	.20	.34	.20
CoO	......	Trace	......	......
NiO	.05	......	......	......
CaO	7.69	1.16	4.94	.23
MgO	32.41	46.68	19.32	8.68
K_2O	.20	.21	.07	.19
Na_2O	.11	.08		
SO_3	.28	......	......	......
	100.86	99.42	100.58	100.10

[1]Discussed by J. S. Diller in Am. Jour. Sci., August, 1886.

	E.	F.	G.	H.	I.
H_2O at 110°	.51	1.40	.85	......	1.94
H_2O at red heat		9.00	2.32	8.78	5.17
CO_2	......	.88	6.29	.55	....
SiO_2	60.56.	35.53	60.78	41.32	60.25
TiO_2	1.19	.95	.03	.48	.23
P_2O_5	.30	.08	.09	.08	.10
Cr_2O_3	......	......	......	Trace	....
Al_2O_3	16.19	18.23	10.54	20.71	20.18
Fe_2O_3	5.19	2.46	3.27	2.59	1.53
FeO	2.41	4.81	......	5.46	3.42
MnO	.36	.13	.10	.17	.10
CaO	2.09	21.17	10.15	9.91	.51
MgO	1.30	2.01	1.59	1.91	3.52
K_2O	4.82	1.08	2.36	.88	3.17
Na_2O	4.78	2.53	1.41	7.19	.39
	99.70	100.26	99.78	100.03	100.51

TRENTON LIMESTONE FROM LEXINGTON, VA.

[Collected by H. D. Campbell. Analyses by R. B. Riggs.]

A. Limestone.
B. Residual deposit from subaërial decay of limestone.

	A.	B.
Ignition	1.08	12.98
CO_2	42.72	......
SiO_2	.44	43.07
Al_2O_3	......	25.07
Fe_2O_3	.42	15.16
CaO	54.77	.63
MgO	Trace	.03
K_2O	......	2.50
Na_2O	......	1.20
	99.43	100.64

RESIDUAL DEPOSIT FROM SUBAËRIAL DECAY OF CHLORITIC SCHIST FROM EIGHT MILES WEST OF CARY, N. C.

[Collected by I. C. Russell. Analysis by R. B. Riggs.]

SiO_2	54.54
Al_2O_3	26.43
Fe_2O_3	9.04
Ignition	9.87
	99.88

YELLOWISH BROWN, KAOLINIZED, DECOMPOSED TRAP FROM FOUR MILES WEST OF SANFORD, N. C.

[Collected by I. C. Russell. Analysis by T. M. Chatard.]

Ignition	13.26
SiO_2	39.55
Al_2O_3	28.76
TiO_2	.64
P_2O_5	.10
Fe_2O_3	16.80
Cr_2O_3	Trace
MnO	Trace
CaO	.37
MgO	.59
Alkali	Undet.
	100.07

ALTERED FELDSPAR FROM LAUREL CREEK, GA.

[Analysis by T. M. Chatard.]

H_2O	8.68
SiO_2	49.25
Al_2O_3	36.33
Fe_2O_3	.09
MnO	None
CaO	3.17
MgO	.64
K_2O	.26
Na_2O	2.16
	100.58

FERRUGINOUS ROCK FROM PENOKEE IRON RANGE,[1] WISCONSIN.

[Collected by R. D. Irving. Analysis by R. B. Riggs.]

SiO_2	15.62
Al_2O_3	4.27
Fe_2O_3	8.14
FeO	32.85
MnO	5.06
CaO	.81
MgO	2.66
CO_2	30.32
H_2O	.68
	100.41

[1] From NE. ¼ of Sec. 6, T. 45, R. 2 E.

TWO ROCKS FROM KAKABIKKA FALLS, KAMINISTIQUIA RIVER, ONTARIO, CANADA.

[Collected by R. D. Irving. Analyses by R. B. Riggs.]

A. Black slate, Animikie formation.

B. Material interstratified with the foregoing.

	A.	B.
SiO_2	37.73	54.26
Al_2O_3	3.41	2.57
Fe_2O_3	6.42	3.62
FeO	22.92	19.63
MnO	.40	.19
CaO	1.26	1.07
MgO	3.98	2.93
CO_2	18.01	14.93
H_2O	2.74	1.20
C	3.54	.45
	100.41	100.85

MICA ANDESITE FROM A CAÑON ON THE EAST SIDE OF SAN MATEO MOUNTAIN, NEW MEXICO.

[Collected by Capt. C. E. Dutton. Analysis by T. M. Chatard.]

Ignition	.14
SiO_2	65.78
TiO_2	.27
P_2O_5	.13
Al_2O_3	17.32
Fe_3O_3	3.68
FeO	.46
MnO	.32
CaO	1.66
MgO	.47
K_2O	4.64
Na_2O	5.23
	100.10

HYPERSTHENE ANDESITE FROM SAN FRANCISCO MOUNTAINS, ARIZONA.

[Collected by Capt. C. E. Dutton. Analysis by T. M. Chatard.]

Ignition	.20
SiO_2	64.82
TiO_2	.56
P_2O_5	.23
Al_2O_3	18.27
Fe_2O_3	3.48
FeO	.56
MnO	.20
CaO	2.89
MgO	.85
Na_2O	5.05
K_2O	2.67
	99.78

BASALT FROM SIX MILES NORTHEAST OF GRANT, NEW MEXICO.

[Collected by Capt. C. E. Dutton. Analyses by T. M. Chatard. Separations of minerals by J. S. Diller.]

A. Basalt.

B. Separated augite.

C. Separated feldspar.

	A.	B.	C.
H_2O	.36	.20	.26
SiO_2	47.54	47.06	52.54
TiO_2	2.76	1.82	Undet.
P_2O_5	.51	.06	....
Al_2O_3	16.73	7.77	31.26[1]
Fe_2O_3	6.69	1.30	
FeO	6.67	8.15	....
MnO	.19	.20	....
BaO	.03	......	Trace
CaO	8.74	19.33	12.34
MgO	6.38	13.52	.28
Na_2O	2.81	.33	3.55
K_2O	1.10	.11	.42
	100.51	99.85	100.65

In B there were traces of Cr, Co, and Ni. Analysis C was made from only .75 gramme of material.

FULGURITE FROM WHITESIDE COUNTY, ILLINOIS.

[Analyses by F. W. Clarke of material selected by G. P. Merrill.]

	Fused glassy portion.	Adjacent sand.
Ignition	.33	1.01
SiO_2	91.66	84.83
Al_2O_3 Fe_2O_3	6.69	9.88
CaO	.38	1.16
MgO	.12	.13
K_2O	.73	1.13
Na_2O	.77	1.50
	100.68	99.64

The fact of the excess of silica in the fulgurite proper was verified by duplicate determinations.

BLUE AND BUFF LIMESTONES FROM QUARRIES OF THE HOOSIER STONE COMPANY, BEDFORD, INDIANA.

[Analyses by F. W. Clarke.]

	Blue.	Buff.
CO_2	43.08	44.01
SiO_2	1.69	.63
Fe_2O_3	.49	.39
CaO	54.18	54.19
MgO	.37	.39
P_2O_5	Trace	Trace
	99.81	99.61

[1] Little Fe_2O_3.

Alkalies undetermined. The color of the buff stone is due largely to organic or carbonaceous matter.

YELLOW SANDSTONE[1] FROM THE ARMEJO QUARRY, COLORADO.

[Analyses by T. M. Chatard.]

A. Analysis (partial) by treatment with strong hydrochloric acid.
B. Analysis by fusion with carbonate of soda.

	A.		B.
Insoluble in HCl	95.54	H_2O	1.19
Soluble:		SiO_2	81.27
Fe_2O_3 Al_2O_3	2.36	Al_2O_3	9.81
CaO	.17	Fe_2O_3	1.44
MgO	.34	CaO	.44
H_2O	1.19	MgO	.42
		Undet	5.43
	99.60		100.00

The undetermined portion under B was probably all alkalies.

EIGHT SAMPLES OF VOLCANIC DUST.

[Series A. From Gallatin Valley, Mont. Collected by A. C. Peale. Analyses by F. W. Clarke.]

[1. Dry Creek Valley, above mouth of Pass Creek. 2 and 3. From near Bozeman. 4. From near Fort Ellis.]

	1.	2.	3.	4.
H_2O	6.45	11.47	6.34	11.96
SiO_2	46.09	61.82	71.01	60.98
Al_2O_3, Fe_2O_3	14.35	19.86	15.17	21.69
CaO	1.61	1.78	1.19	1.83
$CaCO_3$	28.72	....	....	....
MgO	1.29	.51	.34	1.33
K_2O	1.47	1.31	2.97	1.23
Na_2O		2.38	2.77	.80
	99.98	99.13	99.79	99.82

[Series B. Material furnished by G. P. Merrill. Analyses by J. Edward Whitfield.]

[1. From Marsh Creek Valley, Idaho. 2. From Little Sage Creek, Montana. 3. From Devil's Pathway, Montana.]

	1.	2.	3.
H_2O lost at 105°	1.60	1.12	3.46
Ignition	6.00	6.50	5.60
SiO_2	68.92	65.56	65.76
Al_2O_3, Fe_2O_3	16.22	18.24	17.18
CaO	1.62	2.58	2.30
MgO	Trace	.72	Trace
K_2O	4.00	3.94	3.14
Na_2O	1.56	2.08	2.22
	99.92	100.74	99.66

[1] In use as a building stone.

[Series C. From mouth of Bazile Creek, Nebraska. Collected by J. E. Todd. Partial analysis by F. W. Clarke.]

Ignition	4.58
SiO_2	73.67
Al_2O_3 Fe_2O_3	14.33
CaO	.87
MgO	Trace
Alkalies	Undet.

LOESS AND CLAYS.

[Collected by Prof. T. C. Chamberlin. Analyses by R. B. Riggs. Material dried at 100°.]

[A. Typical loess, Kansas City, Mo.]

SiO_2	74.46
Al_2O_3	12.26
P_2O_5	.09
TiO_2	.14
Fe_2O_3	3.25
FeO	.12
MnO	.02
CaO	1.69
MgO	1.12
K_2O	1.83
Na_2O	1.43
H_2O (includes H of organic matter)	2.70
CO_2	.49
C. (organic)	.12
SO_3	.06
Cl	.05
	99.83

[B. Loess from 300 feet above the Mississippi River, 3½ miles northwest of Dubuque, Iowa.]

SiO_2	72.68
Al_2O_3	12.03
TiO_2	.23
P_2O_5	.72
Fe_2O_3	3.53
FeO	.96
MnO	.06
CaO	1.59
MgO	1.11
K_2O	2.13
Na_2O	1.68
H_2O (includes H of organic matter)	2.50
CO_2	.39
C (organic)	.09
SO_3	.51
Cl	.01
	100.22

[C. Loess from seven foot stratum over brown residuary clay, 350 feet above Mississippi River, near Galena, Ill.]

SiO_2	64.61
Al_2O_3	10.64
P_2O_5	.06
TiO_2	.40
Fe_2O_3	2.61
FeO	.51
MnO	.05
CaO	5.41
MgO	3.69
K_2O	2.06
Na_2O	1.35
H_2O (includes H of organic matter)	2.05
CO_2	6.31
C (organic)	.13
SO_3	.11
Cl	.07
	100.06

[D. Loess from center of the city, Vicksburg, Miss.]

SiO_2	60.69
Al_2O_3	7.95
P_2O_5	.13
TiO_2	.52
Fe_2O_3	2.61
FeO	.67
MnO	.12
CaO	8.96
MgO	4.56
K_2O	1.08
Na_2O	1.17
H_2O (includes H of organic matter)	1.14
CO_2	9.63
C (organic)	.19
SO_3	.12
Cl	.08
	99.62

[E. Red, putty-like clay with pebbles, Milwaukee, Wis.]

SiO_2	40.22
Al_2O_3	8.47
P_2O_5	.05
TiO_2	.35
Fe_2O_3	2.83
FeO	.48
MnO	Trace
CaO	15.65
MgO	7.80
K_2O	2.36
Na_2O	.84
H_2O (includes H of organic matter)	1.95
CO_2	18.76
C (organic)	.32
SO_3	.13
Cl	.06
	100.27

[F. Red pebble clay, from 15 feet below Lower Beach deposit, Milwaukee, Wis.]

SiO_2	48.81
Al_2O_3	7.54
P_2O_5	.13
TiO_2	.45
Fe_2O_3	2.53
FeO	.65
MnO	.03
CaO	11.83
MgO	7.05
K_2O	2.60
Na_2O	.92
H_2O (includes H of organic matter)	2.02
CO_2	15.47
C (organic)	.38
SO_3	.05
Cl	.04
	100.50

IRON ORES FROM LOUISIANA.

[Analyses by R. B. Riggs.]

[A. Brown hematite from Bossier Parish, one-half mile west of Bellevue.]

Ignition	11.06
SiO_2	27.85
Fe	39.65
S	.03
Mn	.126
P	.226

[B. Brown hematite from Dr. Whitlaw's, four miles west of Greenwood, Caddo Parish.]

Ignition	10.26
SiO_2	6.37
Fe	50.32
S	.10
Mn	.079
P	Trace

[C. Brown hematite from Simmons's bed, eight miles south of Homer, Claiborne Parish.]

Ignition	10.53
SiO_2	21.77
Fe	43.17
S	.26
Mn	.01
P	.382

[D. Brown hematite from Moreland's, nine miles southeast of Homer, Claiborne Parish.]

Ignition	10.62
SiO_2	10.97
Fe	52.18
S	.03
Mn	.026
P	.064

[E. Brown hematite from 500 feet east of Vienna wire road, Lincoln Parish.]

Ignition	9.05
SiO_2	23.20
Fe	44.54
S	.09
Mn	.006
P	.859

[F. Brown hematite from Lincoln Reed's place, nine miles northwest of Vienna.]

Ignition	9.50
SiO_2	28.12
Fe	39.26
S	.03
Mn	.049
P	.447

[G. Brown hematite from Webster, four miles northwest of Shangaloo.]

Ignition	11.25
SiO_2	18.72
Fe	45.72
S	.17
Mn	.007
P	.247

[H. Brown hematite from Union Parish, one and a half miles north of Downsville.]

Ignition	11.04
SiO_2	21.70
Fe	43.76
S	.03
Mn	.005
P	.835

[I. Brown hematite from Moreland's, ten miles southwest of Arcadia, Bienville Parish.]

Ignition	18.22
SiO_2	39.95
Fe	22.22
S	.17
Mn	.157
P	.072

[J. Limestone from Rayborn's Salt Lick, Bienville Parish.]

SiO_2	.55
$Fe_2O_3Al_2O_3$	1.61
P_2O_5	.048
MnO	Trace
CaO	54.09
MgO	.06
CO_2	44.12
SO_3	.05
	100.528

"NATURAL COKE" FROM MIDLOTHIAN, VA.

[Collected by I. C. Russell. Analysis by R. B. Riggs.]

Water	1.66
Volatile matter	18.35
Fixed carbon	67.13
Ash	12.86
	100.00
Sulphur	4.70

Water in coal dried forty-eight hours over sulphuric acid, 0.11 per cent. Water taken up in forty-eight hours' exposure over water, 3.90 per cent.

COAL FROM JEFFERSON COUNTY, WEST VIRGINIA.

[Bed about fifteen miles west of Berkeley Springs. Analysis by J. Edward Whitfield.]

Moisture	2.30
Volatile matter	10.90
Fixed carbon	81.20
Ash	5.60
	100.00
Sulphur	.785

No coke; ash, pink and sandy.

THREE COALS FROM GULF, NORTH CAROLINA.

[Collected by I. C. Russell. Analyses by F. W. Clarke. Specific gravity determinations made with the Jolly balance by E. L. Howard.]

	Upper layer.	Middle layer.	Lower layer.
Volatile matter	24.48	24.22	23.94
Fixed carbon	72.44	67.86	66.37
Ash	3.08	7.92	9.69
	100.00	100.00	100.00
Sulphur	.99	1.42	3.33
Specific gravity	1.295	1.339	1.359

Coke, good; ash, gray. The coals gain weight on drying at 115°.

COAL FROM WALNUT COVE, STOKES COUNTY, NORTH CAROLINA.

[Analysis by J. Edward Whitfield.]

Water	.38
Volatile matter	17.99
Fixed carbon	55.47
Ash	26.16
	100.00
Sulphur	5.56

No coke. Residue sandy.

"NATURAL COKE" FROM PURGATORY CAÑON, NEW MEXICO.

[Analysis by R. B. Riggs.]

Volatile matter	16.87
Fixed carbon	74.18
Ash	8.95
	100.00
Specific gravity	1.43

TWO SPRINGS, ONE MILE FROM FARMWELL STATION, LOUDOUN COUNTY, VIRGINIA.

[Analyses by R. B. Riggs. Stated in grammes per liter.]

A.

	Found.	Per cent. of total solids.	Hypothetical combination.	
SO_4	1.2865	61.10	KCl	.0067
Cl	.0095	.45	$NaCl$	.0104
CO_3	.1590	7.55	Na_2SO_4	.2355
SiO_2	.0210	1.00	$MgSO_4$	.0750
Al_2O_3	.0070	.33	$CaSO_4$	1.5052
Ca	.5235	24.87	$CaH_2(CO_3)_2$	.1100
Mg	.0150	.71	$CaCO_3$	.1319
K	.0035	.17	Al_2O_3	.0070
Na	.0805	3.82	SiO_2	.0210
	2.1055	100.00		2.1027

B.

	Found.	Per cent. of total solids.	Hypothetical combination.	
SO_4	1.4050	61.28	KCl	.0057
Cl	.0175	.76	$NaCl$	.0244
CO_3	.1730	7.55	Na_2SO_4	.2543
SiO_2	.0110	.48	$MgSO_4$	.0975
Al_2O_3	.0105	.46	$CaSO_4$	1.6363
Ca	.5610	24.47	$CaH_2(CO_3)_2$	.1438
Mg	.0195	.85	$CaCO_3$	.1107
K	.0030	.13	Al_2O_3	.0105
Na	.0920	4.01	SiO_2	.0110
	2.2925	99.99		2.2942

TWO ARTESIAN WELLS, STORY CITY, STORY COUNTY, IOWA.

[Analyses by F. W. Clarke, with carbonic acid determinations by R. B. Riggs.]

[A. Water from artesian well of Thorkill Henryson. Total solids, 0.3620 gramme to liter.]

	Found.	Per cent. of total solids.	Hypothetical combination.	
$Si O_2$	Trace	....	$Si O_2$	Trace
$Fe_2O_3 Al_2.O_3$	.0135	3.73	Fe_2O_3, Al_2O_3	.0135
Cl	.0010	.27	NaCl	.0016
SO_4	None	....	$Na_2 CO_3$	.0417
Ca	.0764	21.10	$Ca CO_3$	.1910
Mg	.0324	8.95	$Mg CO_3$	.1134
Na	.0187	5.17		
CO_2, total	.2680	CO_3 60.56		.3612
		99.78	(99.78 per cent. of total solids accounted for.)	

The CO_2 required in the second and third columns is 0.1607 gramme, leaving 0.1083 gramme for bicarbonates. The water contained flakes of ferric hydroxide.

[B. Water from artesian well of Charles Watkins. Total solids, 0.4710 gramme to liter.]

	Found.	Per cent. of total solids.	Hypothetical combination.	
$Si O_2$	.0250	5.31	$Si O_2$	.0250
$Fe_2 O_3$	.0060	1.28	$Fe_2 O_3$	.0060
Ca	.0796	16.90	$Ca CO_3$	.1990
Mg	.0356	7.56	$Mg CO_3$	.1246
Na	.0501	10.64	$Na_2 CO_3$	.1155
K	Trace	CO_3 58.12		
				.4701
Cl	Trace	99.81	(99.81 per cent. of total solids accounted for.)	
CO_2, total	.3920			

The CO_2 required in the second and third columns is .2008 gramme, leaving .1912 gramme for bicarbonates. The water contained much sediment. Neither water contained any sulphates.

BECK'S HOT SPRINGS, NEAR SALT LAKE CITY, UTAH.

[Analysis by R. B. Riggs. Stated in grammes per liter.]

	Found.	Per cent. of total solids.	Hypothetical combination.	
SO_4	.8405	6.68	KCl	.3761
Cl	6.7438	53.59	NaCl	9.5506
CO_3	.2045	1.63	$MgCl_2$	.4334
SiO_2	.0315	.25	$CaCl_2$	.6957
Al_2O_3	.0090	.07	$CaSO_4$	1.1907
Ca	.6943	5.52	$CaCO_3$	.1262
Mg	.1095	.85	$CaH_2(CO_3)_2$	.1739
K	.1969	1.57	Al_2O_3	.0090
Na	3.7549	29.84	SiO_2	.0315
Li	Trace			
B_2O_3	Trace			12.5871
	12.5849	100.00		

WATER OF MONO LAKE, CALIFORNIA.

[Analysis by T. M. Chatard. Compare old analysis in Bulletin 9, p. 26. Stated in grammes per liter. Specific gravity, 1.0456, 17.°5.]

	Found.	Per cent. of total solids.	Hypothetical combination.	
Na	19.6853	36.790	KCl	1.8342
K	.9614	1.795	NaCl	18.5068
Ca	.0200	.037	Na_2SO_4	9.8690
Mg	.0551	.103	Na_2CO_3	18.6720
Al_2O_3, Fe_2O_3	.0030	.005	$NaHCO_3$	3.9015
SiO_2	.0700	.130	$Na_2B_4O_7$	.2000
SO_4	6.6720	12.470	$CaH_2(CO_3)_2$	.0810
Cl	12.1036	22.630	$MgH_2(CO_3)_2$	.3349
B_4O_7	.1600	.300	Al_2O_3, Fe_2O_3	.0030
CO_2	10.0396	18.770	SiO_2	.0700
O for CO_3	3.2341	6.090		
H_2O in bicarbonates	.4683	.880		53.4724
	53.4724	100.000		

The boric acid is cited from the old analysis, as the material was insufficient for a new determiation.

INDEX.

O

ADVERTISEMENT.

[Bulletin No. 43.]

The publications of the United States Geological Survey are issued in accordance with the statute approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

Except in those cases in which an extra number of any publication has been supplied to the Survey by special resolution of Congress or has been ordered by the Secretary of the Interior, this Office has no copies for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Second Annual Report of the United States Geological Survey, 1880-'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. 1884. 8°. xxxii, 473 pp. 85 pl. and maps.

V. Fifth Annual Report of the United States Geological Survey, 1883-'84, by J. W. Powell. 1885. 8°. xxxvi, 469 pp. 58 pl. and maps.

VI. Sixth Annual Report of the United States Geological Survey, 1884-'85, by J. W. Powell. 1886. 8°. xxix, 570 pp. 65 pl. and maps.

The Seventh and Eighth Annual Reports are in press.

MONOGRAPHS.

Of the Monographs, Nos. II, III, IV, V, VI, VII, VIII, IX, X, XI, and XII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt. U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. Copper-Bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price $1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price $1.05.

VII. Silver-Lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price $1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price $1.10.

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. xx, 338 pp. 35 pl. Price $1.15.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh, 1885. 4°. xviii, 243 pp. 56 l. 56 pl. Price $2.70.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. xiv, 288 pp. 46 pl. Price $1.75.

XII. Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. 1886. 4°. xxix, 770 pp. 45 pl. and atlas of 35 sheets folio. Price $8.40.

The following is in press:

XIII. Geology of the Quicksilver Deposits of the Pacific Slope, with atlas, by George F. Becker.

The following are in preparation:

I. The Precious Metals, by Clarence King.

— Gasteropoda of the New Jersey Cretaceous and Eocene Marls, by R. P. Whitfield.

— Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.

— Lake Bonneville, by G. K. Gilbert.

— Sauropoda, by Prof. O. C. Marsh.

— Stegosauria, by Prof. O. C. Marsh.

— Brontotheridæ, by Prof. O. C. Marsh.

— The Penokee-Gogebic Iron-Bearing Series of North Wisconsin and Michigan, by Roland D. Irving.

— Younger Mesozoic Flora of Virginia, by William M. Fontaine.

— Description of New Fossil Plants from the Dakota Group, by Leo Lesquereux.

— Report on the Denver Coal Basin, by S. F. Emmons.

— Report on Silver Cliff and Ten-Mile Mining District, Colorado, by S. F. Emmons.

— Flora of the Dakota Group, by J. S. Newberry.

— The Fossil Fishes and Fossil Plants of the Triassic Rocks of New Jersey and the Connecticut Valley, by J. S. Newberry.

BULLETINS.

Each of the Bulletins contains but one paper and is complete in itself. They are, however, numbered in a continuous series, and may be bound in volumes of convenient size. To facilitate this, each Bulletin has two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 42 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining values of troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A Catalogue of Geological Maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.

9. Report of work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary Studies, by Charles D. Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin, with Descriptions of New Forms, by R. Ellsworth Call. Introduced by a Sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 3 pl. Price 5 cents.

13. Boundaries of the United States and of the several States and Territories, by Henry Gannett. 1885. 8°. 135 pp. Price 10 cents.

14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.

15. On the Mesozoic and Cenozoic Paleontology of California, by Charles A. White. 1885. 8°. 33 pp. Price 5 cents.

16. On the Higher Devonian Faunas of Ontario County, New York, by John M. Clarke. 1885. 8°. 86 pp. 3 pl. Price 5 cents.

ADVERTISEMENT.

In preparation:

— The Glacial Lake Agassiz, by Warren Upham.
— Notes on the Geology of Southwestern Kansas, by Robert Hay.
— On the Glacial Boundary, by G. F. Wright.
— Geology of the Island of Nantucket, by N. S. Shaler.
— Author Catalogue of Contributions to North American Geology, 1790-1886, by Nelson H. Darton.
— The Gabbros and Associated Rocks in Delaware, by F. D. Chester.
— Report on the Geology of Louisiana and Texas, by Lawrence C. Johnson.
— Fossil Woods and Lignites of the Potomac Formation, by F. H. Knowlton.
— Contributions to the Mineralogy of the Pacific Coast, by W. H. Melville and Waldemar Lindgren.

STATISTICAL PAPERS.

A fourth series of publications, having special reference to the mineral resources of the United States, has been undertaken.

Of that series the following have been published:

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Mineral Resources of the United States, 1885. Division of Mining Statistics and Technology. 1886. 8°. vii, 576 pp. Price 40 cents.

In press:

— Mineral Resources of the United States, 1886, by David T. Day. 1887. 8°.

Correspondence relating to the publications of the Survey and all remittances (which must be by POSTAL NOTE OR MONEY ORDER, not stamps) should be addressed

TO THE DIRECTOR OF THE
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

WASHINGTON, D. C., *November* 30, 1887.

DEPARTMENT OF THE INTERIOR

BULLETIN

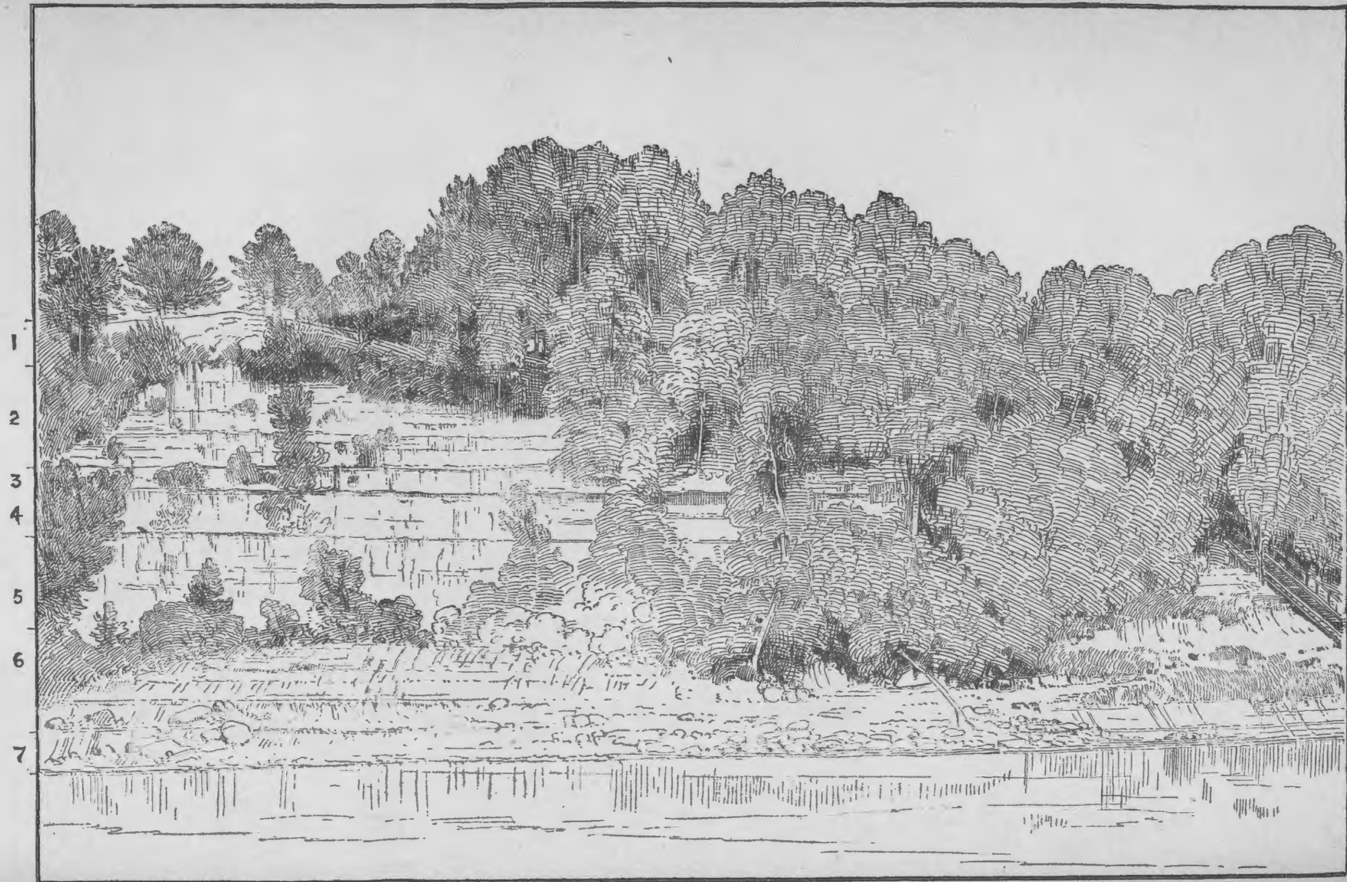
OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 43

WASHINGTON
GOVERNMENT PRINTING OFFICE
1887



1. Red loam with pebbles and sand. 2. White limestone. 3. *Scutella Lyelli* bed, with subjacent ferruginous sands. 4. Claiborne sand. 5. Calcareous clay etc. (*O. sellæformis*). 6. Calcareous sand. 7. Blue clay with greensand.

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

TERTIARY AND CRETACEOUS STRATA

OF THE

TUSCALOOSA, TOMBIGBEE, AND ALABAMA RIVERS

BY

EUGENE A. SMITH

AND

LAWRENCE C. JOHNSON

WASHINGTON

GOVERNMENT PRINTING OFFICE

1887

CONTENTS.

VI. RÉSUMÉ.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

GEOLOGICAL SURVEY OF ALABAMA,
Tuscaloosa, Ala., November 30, 1886.

SIR: I have the honor to transmit herewith a report on the observations of Mr. L. C. Johnson, of the U. S. Geological Survey, and myself on the Tertiary and Cretaceous strata exposed along the Tuscaloosa, Tombigbee, and Alabama Rivers in this State, made under instructions from you during the summer of 1883, together with my own subsequent observations.

Although the report is a preliminary one and further investigations in the same region are now in progress, recent publications have excited such interest in the Tertiary and Cretaceous formations in the Southern States as to justify immediate publication.

I have the honor to be, sir, with great respect, very truly yours,

EUGENE A. SMITH,
State Geologist of Alabama.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

PREFACE.

During the summer of 1883 a trip was made by the authors, in a small steamer, down the Tuscaloosa (also called Black Warrior or Warrior) River, from Tuscaloosa to its confluence with the Tombigbee, down the latter stream to its confluence with the Alabama, down the Alabama and Mobile Rivers to the head of Mobile Bay, and thence up the last two rivers to Prairie Bluff. This route, the localities of the accompanying detailed sections, and other points mentioned in the text are indicated in the accompanying geologic map of Alabama forming Plate XI. The trip by steamer was made at the joint expense of the U. S. Geological Survey and the Geological Survey of Alabama.

The first draft of this bulletin was prepared with the data collected during this trip, there being added thereto information gathered by myself in 1872, 1880, 1881, 1882, and 1884 for the Geological Survey of Alabama and for the Tenth Census of the United States and information obtained by Mr. L. C. Johnson in 1881, 1882, and 1883. The bulletin was not completed until I had gone over the whole ground again, in the summer of 1885, in company with Messrs. T. H. Aldrich and D. W. Langdon, of the Geological Survey of Alabama. Finally, the results of my investigations in the same region during the summer of 1886 have been in large part incorporated. Though it is believed that the accompanying sections of the Tertiary and Cretaceous strata of Alabama are much more nearly complete and more trustworthy than anything hitherto published, it should be said that the paleontologic material has not yet been fully examined, and that the Ripley, Eutaw, and Tuscaloosa formations require some further investigation. The present report must, therefore, be regarded as a preliminary one.

The photographic views from which some of the illustrations have been prepared were taken during the summer of 1885. It is greatly to be regretted that some of the photographic plates of important localities were spoiled by dampness before prints could be obtained from them.

The authors desire to express their indebtedness to Mr. W J McGee, of the U. S. Geological Survey, for assistance kindly given in the preparation of the present report, and particularly for the discussion of the age of the Tuscaloosa formation and for the résumé of results.

Both authors co-operated in the field work and in the preliminary discussion of the observations; but the present writer is responsible for the arrangement of the matter of the report, the plates, and the maps. The manuscript, however, has received the approval of the associate author.

EUGENE A. SMITH.

TERTIARY AND CRETACEOUS STRATA OF THE TUSCALOOSA, TOMBIGBEE, AND ALABAMA RIVERS.

BY E. A. SMITH AND L. C. JOHNSON.

INTRODUCTION.

In a memoir on the geological history of the Gulf of Mexico, published in 1871, Dr. E. W. Hilgard gives in descending order the following subdivisions of the Tertiary and Cretaceous in the Gulf States:[1]

			Feet.
Post-Eocene Tertiary	Grand Gulf group (brackish)		250
Eocene Tertiary	Vicksburg	Marine group	120
	Red Bluff		12
	Jackson		80
	Claiborne		60
	Buhrstone		150
	Lagrange	Lignitic group	450
	Flatwoods		
Cretaceous	Ripley group		350
	Rotten Limestone group		1,200
	Coffee (or Eutaw) group		300–400

Professor Angelo Heilprin,[2] using the publications of E. W. Hilgard, M. Tuomey, T. A. Conrad, C. S. Hale, C. Lyell, and A. Winchell, and manuscript notes furnished by the writer in 1873, has compiled the following section of the Eocene strata in Alabama:[3]

	Feet.
White Limestone (Jacksonian)	50
Claibornian	17
Buhrstone (Silicious Claiborne of Hilgard)	250
Wood's Bluff and Bashi (Eolignitic)	50 ?

Our observations compel us to modify slightly the nomenclature of these authors and to modify materially their estimates of the thickness of the formations.

We are led to revive Tuomey's term White Limestone,[3] and apply it to the Vicksburg, Red Bluff, and Jackson divisions of Hilgard, since

[1] Proc. Am. Assoc. Adv. Sci., Vol. XX, p. 222, 1871; also Am. Jour. Sci., 3d ser., Vol. II, p. 391 and map, 1871.

[2] Contrib. to the Ter. Geol. and Pal. of U. S., pp. 29, 30, 1884.

[3] First Bien. Rep. Geol. Ala., p. 154, 1850.

the collections recently made by Mr. T. H. Aldrich, but not yet described, show that there are very few fossils severally peculiar to any of these quasi-formations; and we are disposed to refer the several strata to the Upper Eocene. We are also led to divide the Claiborne of Hilgard into two formations, corresponding to his Calcareous Claiborne and Silicious Claiborne, respectively, and to restrict the term to the upper. We follow Tuomey[1] and others in denominating the lower formation the Buhrstone. Again, we are unable to discriminate the Lagrange and the Flatwoods of Hilgard; and we find the formation including these divisions to include also several beds containing marine fossils.[2]

The three Cretaceous formations are easily distinguishable along our rivers as distinctive rock masses; but in constructing our sections we have been constantly confronted with the difficulty of fixing their boundaries with precision, since they appear to shade into one another, lithologically at least, by almost imperceptible gradations. Thus we are not sure that any of the outcrops along either of the rivers show the contact of the Ripley beds with the upper part of the Rotten Limestone. The contact of the lowermost strata of the latter formation with the underlying sandy beds is clearly enough seen at several places, at Erie and Choctaw Bluff, Tuscaloosa River, and at House Bluff, Alabama River, &c.; but below the first 15 or 20 feet of these sands the strata for nearly 300 feet (and, indeed, to the base of the Tuscaloosa formation, perhaps 1,000 feet lower still) are exceedingly poor in fossil remains, except those of vegetable origin, and even these are almost indeterminable. Dr. Hilgard considers these fossiliferous sands (his Tombigbee Sand group) as more nearly allied to the Rotten Limestone than to the Eutaw group, and if we class them with the former then the line between the Rotten Limestone and the Eutaw groups will come somewhere within the first 20 feet or so below the base of the calcareous part of the Rotten Limestone. The limit between the Eutaw and the Tuscaloosa formation, in like manner, is ill defined. It may further be mentioned that we have not seen in Alabama any beds which we can identify as belonging to the Grand Gulf age.

Our estimates of thicknesses vary considerably from those of Hilgard, partly, at least, because his estimates do not represent the thick-

[1] First Bien. Rep. Geol. of Ala., p. 143, 1850.

[2] This formation has been denominated Eolignitic by Heilprin (Proc. Acad. Nat. Sci. Phila., p. 159, 1881); but the law of priority demands the retention of the name Lignitic, which was used in the same sense by Hilgard in 1860 or earlier. Once more, we feel compelled to restrict the name Eutaw to the glauconitic sands, laminated clays, micaceous sands, &c., beneath the Tombigbee sand and above the Big Log Shoals horizon. And, finally, for reasons stated fully on a subsequent page, we apply the name Tuscaloosa formation to the fossiliferous clays, purple clays and associated rocks exposed on the Tuscaloosa River from Tuscaloosa to White Bluff and at many localities between the Tuscaloosa and Alabama Rivers.

ness at any one locality, but the maxima in the Gulf States, and partly because our estimates are based on careful measurements of actual exposures of which only a part have hitherto been examined.

Since our route described two approximately parallel lines at right angles to the strike of the strata, we have generally been able to supply the breaks in continuity of exposures along one river by satisfactory exposures at corresponding stratigraphic horizons on the other, or at some points inland but contiguous to the water courses.

In the Tertiary formations at two horizons only have we been unable, by the combination of undoubtedly overlapping sections, to perfect our stratigraphic column. These breaks, which, upon an assumed uniform dip of 30 to 40 feet to the mile, cannot involve more than 50 feet each, probably much less, we have left blank. The black clays at the base of the Tertiary are exposed along the Tombigbee River from Black Bluff to Naheola, a distance which, with such a dip as that assumed, would correspond to a thickness of 260 feet.[1] These clays are much thinner on the Alabama River, and in the Bladen Springs boring, as we interpret it, the thickness is about 100 feet, which we have adopted in our section. The apparently much greater thickness indicated by the exposures along the Tombigbee is probably due to undulations in the strata.

Our estimate of the total thickness of the Tertiary formations, ranging from 1,630 to 1,700 feet, is considerably larger than any hitherto made. It is, however, a minimum, as may be seen from our plates giving the overlapping sections from which the stratigraphic column has been constructed. This estimate finds a strong corroboration in the records of borings made in Meridian, Miss., and at Bladen Springs, Ala. The former boring was commenced in the upper strata of the Lignitic, just beneath the Buhrstone, and it is certain that the Rotten Limestone of the Cretaceous was not reached at a depth of 980 feet. At Bladen Springs the surface rocks are the Hatchetigbee beds, immediately underlying the Buhrstone. In this boring the Rotten Limestone was reached at 1,220 feet and the boring terminated in that formation at a depth of 1,345 feet Accordingly, while our estimates of the aggregate thickness of the Tertiary formations of the Alabama and Tuscaloosa Rivers doubtless include minor errors, we have, we believe, a nearly complete and generally accurate section of the strata exposed on these rivers.

In the case of the Cretaceous our observations have less completely covered the ground, and we have been forced in some instances to rely upon estimates based upon an assumed seaward dip of the strata of 40 feet to the mile. This rate of dip agrees with the average of our obser-

[1] A re-examination of the exposures of these black clays in the summer of 1886 has convinced me that no reliance can be placed upon the dip in estimating the thickness, for the clays undulate very considerably. One bed in the black clay, for instance, was traced down the river (across the strike) for several miles, with scarcely any change in its height above the water level.—E. A. S.

vations and is corroborated by the record of the boring for an artesian well at Livingston, in Sumter County. The thickness of Rotten Limestone penetrated in this boring is 930 to 950 feet, and the width of the belt in which this is the surface rock in this part is about twenty-four miles across the strike of the strata. In the Ripley division we have, we think, a nearly complete section from our observations. In the Rotten Limestone we have the record of the Livingston well. In the Eutaw formation we have to rely in some degree upon estimates, though we have at Eutaw, on the Tuscaloosa, and at House Bluff and at Cunningham Bluff, on the Alabama, as we believe, nearly if not quite the complete series.

The materials of the Tuscaloosa formation, clays and loose sands, make comparatively little show along the Tuscaloosa River. Our column of this formation is accordingly very imperfect, and the estimate of thickness is based altogether upon an assumed dip of the strata of 40 feet to the mile.

The following table exhibits, in condensed form, our subdivisions of the Tertiary and Cretaceous formations of Alabama as exposed along the Tuscaloosa, Tombigbee, and Alabama Rivers, together with the carefully estimated thickness of each:

				Feet.
Tertiary (Eocene).	Upper	White Limestone	Coral Limestone (Vicksburg ?)	150
			Vicksburg (orbitoidal)	140
			Jackson	60
	Middle.	Claiborne		140–145
		Buhrstone		300
	Lower	Lignitic	Hatchetigbee	175
			Wood's Bluff	80–85
			Bell's Landing	140
			Nanafalia	200
			Matthews's Landing and Naheola	130–150
			Black Bluff	100
			Midway	25
Cretaceous		Ripley		250–275
		Rotten Limestone		1,000
		Eutaw		300
Cretaceous (?)		Tuscaloosa		(?) 1,000

Our investigations relate chiefly to the formations below the White Limestone, and more especially to those underlying the Buhrstone, of which, so far as we are aware, no connected account has hitherto been published.

Our itinerary notes have been assembled and digested and the various exposures of the two water ways are described together in the inverse order of antiquity. The leading phenomena are recapitulated in the description of the general section.

I.—TERTIARY STRATA.

§1. THE WHITE LIMESTONE.

As already stated, we include in this formation both the Vicksburg and the Jackson group of Conrad, Hilgard, and others, as well as the Red Bluff group of Hilgard, if it is developed in Alabama. The recent very extensive collections of Mr. T. H. Aldrich have shown that, with very few exceptions, the same shells are common to the Vicksburg and to the Jackson bed. Certain lithological and paleontological differences may easily be observed in the different parts of this formation, as set forth below, but these differences do not, in our opinion, justify us in dividing a formation which, in Alabama, so clearly presents itself as a unit. The term White Limestone has been used by Professors Tuomey and Winchell and by other geologists as representing both of the above groups, though most of the writers on Alabama Tertiary geology have called attention to certain differences existing between the upper and the lower parts of the formation as exhibited at the bluff at St. Stephens.

The term, moreover, is popularly used to designate this whole series of limestone rocks throughout the region in which it occurs. As above stated, it is in this sense that we also wish to use it, and we do not intend to confine the term, as does Heilprin, to the lower 60 feet, which corresponds to the Jackson division.

The thickness of the White Limestone in Alabama we believe to be not less than 350 feet, and our estimates are based upon the following facts: About half a mile from the Claiborne bluff, on the road to Perdue Hill, White Limestone filled with *Orbitoides Mantelli* Mort. occurs at least 200 feet above the base of the argillaceous White Limestone (Jackson) which immediately overlies the Claiborne fossiliferous sands. At this locality, therefore, we have undoubtedly 200 feet of limestones belonging to this division of the Tertiary. At Salt Mountain, 150 feet of a coral limestone overlies the uppermost of the beds with *Orbitoides Mantelli*, and this, added to the orbitoidal and argillaceous limestones seen at Claiborne, gives what we consider to be the minimum thickness of the White Limestone.

As regards the classification of the White Limestone in the Tertiary series, opinions vary. Conrad says:[1] "The Claiborne group I regard as newer Eocene, the Jackson as older Oligocene, and the Vicksburg group as newer Oligocene."

Heilprin[2] also puts the Vicksburg and the Jackson together as Oligocene, though elsewhere in the same volume he speaks of the Vicksburg alone as Oligocene and places the Jackson with the Eocene as its uppermost member.

[1] Geol. N. C., Vol. I, Appendix A, p. 25, 1875.

[2] Contrib. to the Tert. Geol. and Pal. of the U. S., p. 33.

The view of Conrad was at first adopted by us, but subsequently the study of extensive collections made by Mr. Aldrich at Jackson and Vicksburg, the finding by him of *Venericardia planicosta* in the uppermost beds of the White Limestone near Claiborne, and other circumstances have led us to think that there is no good reason for separating any part of our White Limestone from the Eocene, and we have no strata in Alabama which we regard as Oligocene.

It is to be remarked that nowhere in Alabama have any deposits yet been found comparable with the fossiliferous beds of Jackson and Vicksburg in Mississippi, as regards either the excellence of preservation or the number and variety of the fossils; for, with the exception of *Orbitoides Mantelli*, *Pecten perplanus* Mort., *Zeuglodon cetoides*, and a few others, fossils are comparatively rare in the Alabama White Limestone.

DIVISIONS OF THE WHITE LIMESTONE.

The few forms, however, which do occur here appear to be generally restricted to a definite horizon, and we recognize in every locality of its occurrence two divisions of the White Limestone, and in one place three divisions, each distinguished by peculiarities in its lithological characters and in its fossils.

The *uppermost division*, 150 feet in thickness, has as yet been observed in one locality only, viz, at Salt Mountain at the Middle Salt Works in Clarke County. The rock here, is a hard, white limestone, composed in great measure of masses of corals partly silicified. Near the base of this rock there occur great numbers of the spines and plates of echinoderms.

The *middle division* of the White Limestone has a thickness of at least 140 feet. Lithologically it varies considerably, being in part a hard, crystalline limestone weathering into rough, irregularly shaped pieces, which have suggested the name "horsebone" rock, popularly used to designate it. Another variety is a soft, sometimes pulverulent mass of nearly pure carbonate of lime, which is everywhere quarried for building purposes. When fresh, this rock may easily be cut with an ax or a saw, but it hardens on exposure to the air and lasts for many years in chimneys and pillars to houses. This part of the White Limestone contains as a characteristic fossil *Orbitoides Mantelli*, often in such numbers that the rock is little more than a mass of the disks of orbitoides packed in soft, white carbonate of lime. The orbitoides are most abundant in the upper two thirds of this division, becoming less and less abundant below this.

The *lower division* of the White Limestone, about 60 feet in thickness, is in general terms a light colored, argillaceous limestone resembling the Rotten Limestone of the Cretaceous formation both in the character of the rock and in that of the soils to which it gives rise on disintegration. It is traversed by thin bands of tolerably pure, white limestone and by beds of slightly calcareous clay, the latter often impregnated with gypsum. In places it is strongly glauconitic. This division contains a greater variety of fossils than either of the other two, though probably a smaller number. The fossils appear in general to be much more abundant in the upper half of the rock, where the more commonly occurring species are *Pecten perplanus* Mort., *Spondylus dumosus* Mort., *Ostrea cretacea* Mort., sharks' teeth, bones of *Zeuglodon cetoides*, and *Terebratula lachryma* Mort. This upper and most highly fossiliferous part holds calcareous clays which are strongly phosphatic and occasionally well filled with phosphatic or coprolitic nodules. The lower half of this division, while less fossiliferous than the preceding, has in nearly every locality examined a bed near its base at least three feet in thickness holding vast numbers of *Scutella Lyelli* Con. This, which we have called the Scutella bed, has often served us as a guide in the study of this formation in the field, since it overlies by a few feet only the Claiborne fossiliferous sands.[1]

This lower division of the White Limestone has usually been considered the equivalent of the Jackson, and the overlying orbitoidal rock (middle division) the equivalent of the Vicksburg group of Mississippi, and there seems to be no reason to doubt the correctness of the identification. The uppermost division has been observed or recognized only at one locality (Salt Mountain), but it will probably be found to belong to the Vicksburg group.

The following sections (see Plate XII, p. 143) exhibit the characters of two phases of the White Limestone as they are exposed along the two rivers, and a third phase seen in the lower part of Clarke County between the rivers.

(*a*) About six miles south of Jackson, in Clarke County, at the Central Salt Works, I obtained in the summer of 1885 a section of the uppermost of the White Limestone rocks which overlie the orbitoidal rock. These rocks, which are seen in actual contact with the orbitoidal limestone, form the summit of the White Limestone formation in Alabama, so far, at least, as our observation goes. At this locality, Salt Creek flows at the base of a hill rising 150 feet above the water level and composed of limestone in which the only recognizable fossils are spines and plates of echinoderms and great masses of corals. These corals make up a very considerable proportion of the hill. A few hundred yards from the base of the hill a thickness of about twenty feet of the orbitoidal rock, such as is used in the vicinity for building purposes, is exposed, and in such position as to show unmistakably that it underlies the coral rock of the hill just mentioned, which has the local name of Salt Mountain. (See Plate XII, Fig. 1, p. 143.)

[1] The rocks of the Claiborne group are distinguished from those of the White Limestone by the presence of glauconite in large proportion, and this Scutella bed is the first of the ferruginous beds of the Tertiary. We are undecided whether this Scutella bed should go with the White Limestone or with the Claiborne, since the fossil is found in both formations.

(*b*) The bluff at Saint Stephens on the Tombigbee River (Plate II), about one hundred feet in height, exhibits both of the commonly occurring phases of the White Limestone, viz, the middle and lowermost. (See Plate XII, Fig. 2, p. 143.) The uppermost 70 feet of this bluff consists of the soft White Limestone, which is extensively quarried for building chimneys. *Orbitoides Mantelli* occurs throughout this rock, but is particularly abundant in the uppermost 20 or 30 feet. Below the orbitoidal rock to the water's edge the limestone is rather argillaceous and holds in places great numbers of *Spondylus* (*Plagiostoma*) *dumosus* and other fossils which are usually considered characteristic of the Jackson group. In this part of the bluff, Mr. D. W. Langdon, jr., of the Alabama Geological Survey, in 1884 discovered phosphatic nodules and a phosphatic marl, a more detailed description of which will be found in a forthcoming Alabama State Geological Report. In this connection it may be proper to say that in the summer of 1885 we found that a phosphatic marl occurs in the lower or Jackson division of the White Limestone everywhere in Choctaw, Clarke, and Monroe Counties.

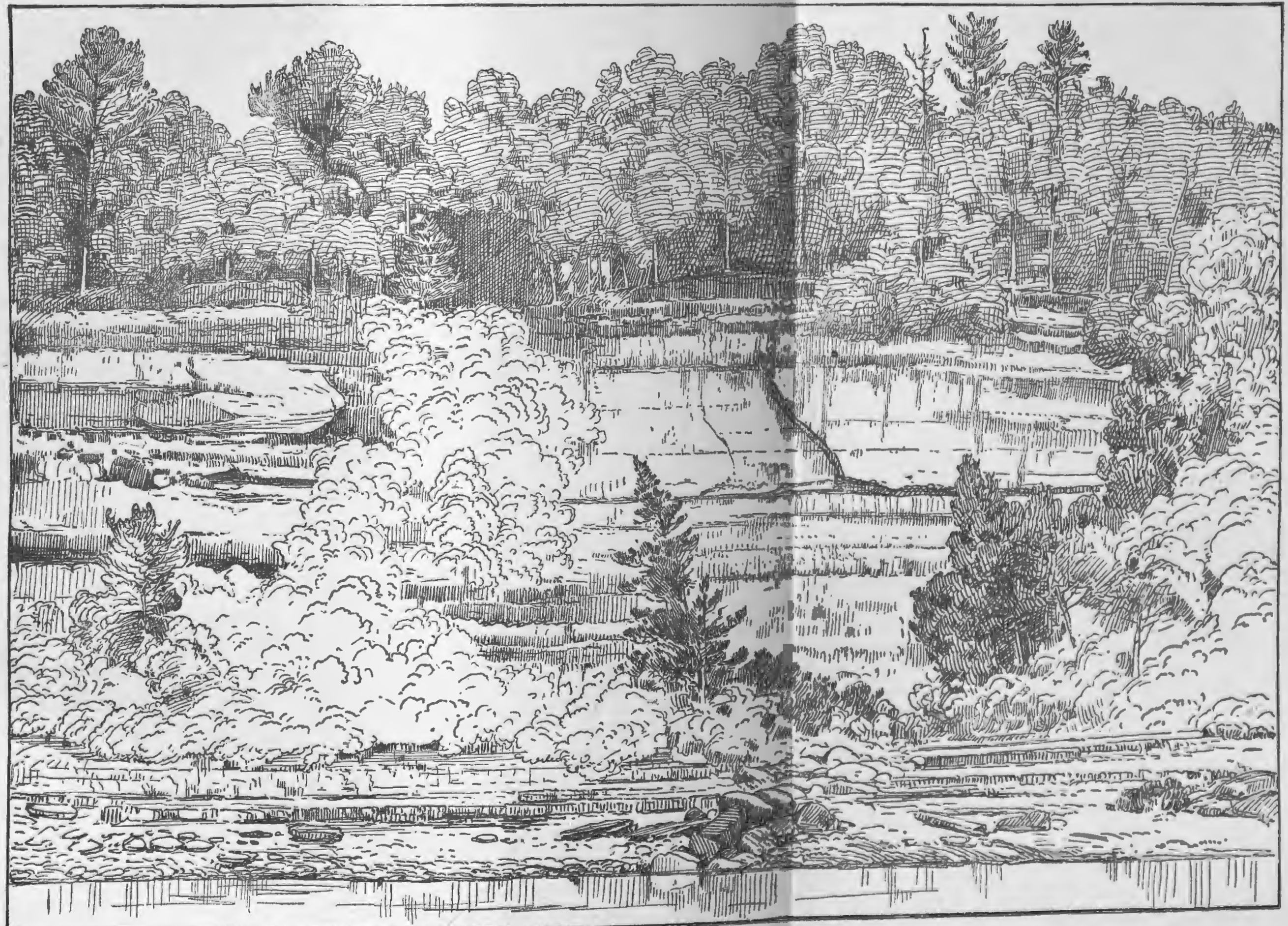
(*c*) About half a mile above Saint Stephens Bluff, and in plain sight of it, is Gopher or Baker's Hill, where the actual contact of the limestones of Saint Stephens Bluff with the ferruginous sands of the Claiborne formation may be clearly seen.

The following section of Baker's Hill should set forever at rest the question of the relative positions of the strata concerned (see Plate XII, Fig. 3, p. 143).

Section at Baker's Hill, Tombigbee River.

1. Orbitoidal limestone forming summit of the hill. This limestone is the same as that forming the upper part of the Saint Stephens Bluff, half a mile distant .... 20 to 30 feet.
2. Argillaceous limestone with *Pecten perplanus* Mort. and *Pecten Poulsoni* Mort. in its upper part and with hard ledges in lower part .... 55 to 60 feet.
   This rock is the same as that at the base of Saint Stephens Bluff, but only 15 to 20 feet of it are to be seen above water at the latter place.
3. Bed with *Scutella Lyelli* in great numbers, 1 foot seen, at other points .... 3 feet.
4. Coarse grained, ferruginous sands, passing downwards into reddish, ferruginous sands, with the characteristic fossils of the Claiborne sands, viz, *Melongena alveata* Con., *Crepidula lirata* Con., *Infundibulum trochiformis* Con., *Corbula Murchisoni* Lea, *Turritella lineata* Lea, *Cytherea æquorea* Con., *Oliva Alabamensis* Con., *Turbinella pyruloides* Con., *Turbinolia Maclurei* Lea, *Voluta Defranckii* Lea, *Astarte sulcata* Lea, &c .... 15 to 18 feet.
5. Bluish green, glauconitic sands and clayey sands containing a *Flabellum* similar to that found at Claiborne and at Coffeeville .... 8 to 10 feet.
6. Hard ledge at water's edge at upper end of bluff .... 1 foot.

(*d*) During the summer of 1885 many localities were visited in Choctaw and Clarke Counties where the White Limestone and the Claiborne sands are to be seen in contact, so that there can be no possible doubt as to their relative position, unless we assume that the strata have been overturned, and of this there is not a shadow of proof. Some of the localities were also visited by Professor Tuomey and by Prof. A.



ST. STEPHENS BLUFF, TOMBIGBEE RIVER

Winchell, while some have not yet been referred to in any published document. These localities will be given below, under Claiborne group.

Professor Tuomey[1] says that the Buhrstone, after dipping below the surface in the upper part of Clarke County, emerges again at the Lower Salt Works, in the southern part of the county. Our visit to this place in 1883 confirmed this statement of Professor Tuomey, but there were many things observed in the distribution of the rocks in Clarke and Choctaw Counties which were difficult of explanation so long as we confined our attention to the banks of the rivers.

During several excursions by land through these counties previous to 1883 and again in the summer of 1885, the present writer was able to collect the data which prove that the basin in Clarke County, referred to by Professor Tuomey, is by no means a simple syncline, but includes several undulations, by which the Buhrstone rocks are again brought to the surface of the country at several points to the southward of the line where they first dip below it. It is by reason of these irregularities that the southernmost exposures of the Tertiary rocks along the rivers are not made by the uppermost rocks of the White Limestone series, but in the case of Choctaw Bluff, at least, by those of the Jackson or lower division of the White Limestone.

Section at Choctaw Bluff, Clarke County.

1. Drift, pebbles and sand, capped with red loam....20 feet.
2. Bluish clay....5 feet.
3. Greenish clay....5 feet.
4. White argillaceous limestone or indurated marl, containing many large specimens of *Ostrea Georgiana*, *Scutella Lyelli*, *Pecten Poulsoni*, many tubes of *Aspergillum* or allied genus, and obscure casts of other fossils....5 feet.

The bluish clay (No. 2) contained in many places lignitized or half lignitized stumps, while the underlying greenish clay contained no fossils.

At Gainestown, a few miles above Choctaw Bluff, there is another exposure of the White Limestone. The principal rock at this place is a heavy bedded, yellowish limestone with *Orbitoides Mantelli*. This rock has been quarried for building purposes, and several large blocks of it are to be seen on the river bank at Choctaw Bluff, whither they were carried during the war. The tubes of Aspergillum are also to be seen at several places near Gainestown, and some of the clays there hold a very considerable amount of gypsum crystals, as described by Mr. E. Q. Thornton,[2] who also says that the bones of Zeuglodon have been found a few miles from the Gainestown Landing. From these circumstances it appears that a part, at least, of the strata at Gainestown is of the Jackson horizon.

(*e*) From Marshall's Landing, some miles above Gainestown, up to Claiborne, the bluffs on both sides of the river give a very complete

[1] First Bien. Rep. Geol. Ala., p. 150, 1850.

[2] Second Bien. Rep. Geol. Ala., pp. 250 251, 1858.

and almost uninterrupted section, with none of the irregularities noticed on the Tombigbee, since all the strata show a gentle southerly dip.

At Marshall's Landing, the upper part of the bluff consists of the orbitoidal limestone, the lower part of the argillaceous limestone of Jackson age, and from this point up to the mouth of Cedar Creek the other beds of the Jackson series form the low bluffs of the river, from which a very good section has been made, as follows:

Section of White Limestone strata, Alabama River.

1. Orbitoidal White Limestone of the usual character ....10 feet.
2. White Limestone containing *Scutella Lyelli* in numbers ....10 feet.
   This is the base of the Vicksburg or Orbitoidal Limestone, which, as we have seen at Claiborne, has a thickness of 140 feet, and at Salt Mountain has 150 feet of a coral limestone above it.
3. Effervescent or calcareous, joint clay, in two beds, each 5 or 6 feet in thickness, separated by 3 feet of soft, earthy White Limestone; below this a harder ledge of limestone, and then about 8 feet of blue clay, passing into a blue, calcareous clay or marl, making in all .... about 24 feet.
4. Earthy white limestone, resembling the Rotten Limestone of the Cretaceous formation .... about 25 feet.
   (This limestone has at intervals of 3 or 4 feet, ledges of similar but harder material projecting slightly from the faces of the bluff. These ledges vary from one to three feet in thickness.
5. Scutella bed (*S. Lyelli*), consisting of 3 layers: (*a*) a limestone, with a few *Scutellas* (*S. Lyelli*), 1 foot; (*b*) a ferruginous sand filled with the same *Scutella*, 1 foot; (*c*) a white limestone bed similar to (*a*) and 1 foot thick .... 3 feet.
   Beneath this is a bed of coarse grained, ferruginous sand, extending down to the water ....1 or 2 feet.
   This bed is seen at Rattlesnake Bluff, Claiborne.

These relations are shown in the section. (See Plate XII, Fig. 4, p. 143.)

(*f*) The upper part of the bluff at Claiborne is also composed of the argillaceous White Limestone of the Jackson age, and as we ascend the hill back of Claiborne, leading up to Perdue Hill (2 miles), the orbitoidal limestone appears in gullies and wherever the surface soil has been removed, up to an elevation of 90 or 100 feet above the top of the river bluff. This is precisely the position which the White Limestone occupies with reference to the Claiborne sands at Baker's Hill on the Tombigbee, as well as at other localities in Clarke County, referred to above. (See Plate XII, Fig. 5, p. 143.)

The White Limestone is the surface rock over a very considerable part of Choctaw, Washington, Clarke, Monroe, Conecuh, Covington, and Geneva Counties. Where the lower or more argillaceous portion of it forms the surface, it gives rise, upon disintegration, to a limy soil, very similar to that of the Rotten Limestone of the Cretaceous group, but the topography is much more broken, justifying the name of Lime Hills, which I have given to this region in the Report of the Geological Survey of Alabama for 1881–'82. These Lime Hills may be followed from Choctaw and Washington Counties, without a break, into

Mississippi, and there can be no doubt as to their identity with the Jackson prairies of Professor Hilgard.

It is in these Prairie Hills that the Zeuglodon bones are always found. Other commonly occurring fossils are *Pecten perplanus*, *Spondylus dumosus*, *Scutella Lyelli*, a species of Ostrea, and a Cassis similar to one occurring at Red Bluff in Mississippi.

§ 2. THE CLAIBORNE.

The beds which in Alabama intervene between the base of the White Limestone and the top of the Lignitic division, and which are at least 450 feet in thickness, may be divided into two groups, of very unequal thickness, which exhibit very marked differences in their lithological features and in the relative abundance and variety, though perhaps not in the specific characters, of their fossil contents.

The upper group, 140 to 150 feet in thickness, constituting the *Claiborne beds proper*, consists of ferruginous sands, calcareous sands, and calcareous clays, generally glauconitic. These beds are mostly loose and incoherent, crumbling easily and giving rise to no marked topographic features in the region which they immediately underlie. This whole group is distinguished by the abundance and the variety of its fossils. Near the top of the series is the bed of ferruginous sand which has furnished the greater part of the celebrated Claiborne fossils. The calcareous sands underlying for 60 feet the ferruginous Claiborne sand above named are clearly marked by the great numbers of the shells of *Ostrea sellæformis* which they contain. Below these beds are glauconitic sands and clays holding a great variety of well preserved shells.

The lower group, about 300 feet thick, consists of silicious and aluminous sandstones and indurated clays, with occasional glauconite beds; all, except a few thin beds with marine shells, containing very little lime and, by comparison with the preceding group, very few fossils. These rocks are mostly hard and resistant and form some of the highest and most rugged hills in the southern part of the State. To this series of rocks Professor Tuomey[1] has given the name *Buhrstone*, and has pointed out their identity with the Buhrstone rocks of South Carolina and Georgia.

Prof. E. W. Hilgard[2] placed these two together under the head of the Claiborne group, distinguishing the upper and lower divisions as the Calcareous and the Silicious Claiborne strata, respectively. From the section given in Hilgard's Report,[3] it seems that the middle part of what we have called the Claiborne series, containing the great numbers of *Ostrea sellæformis*, are the beds of the Calcareous division, best developed in that State. The Silicious Claiborne or Buhrstone strata are found in

[1] First Bien. Rep. Geol. Ala., p. 150, 1850.

[2] Rep. on Geol. and Agric. of Mississippi, pp. 108, 123, and 126, 1860.

[3] Rep. on Geol. and Agric. of Mississippi, pp. 126, 127, 1860.

great thickness in Mississippi and present practically the same features as in Alabama. The rugged Buhrstone hills of Clarke, Lauderdale, Newton, Kemper, Neshoba, and Leake Counties, in Mississippi, have their counterparts in Choctaw, Clarke, and Monroe Counties in Alabama.

The fossiliferous greensands mentioned by Professor Hilgard,[1] in connection with the Silicious Claiborne, were afterwards (1871) traced by the writer from Marion, in Mississippi, across the State to the Mississippi bottom in Holmes and Carroll Counties.

As already indicated above in our tabular presentation, we adopt here Professor Tuomey's division of these strata into Claiborne and Buhrstone.

The lithological and other characters of the Claiborne beds have been stated above in the most general terms. A few additional details will suffice to give a fair conception of the general features of the Claiborne formation. Near the top of the series we find a bed varying from 15 to 17 feet in thickness, which, at Claiborne, Gosport, Rattlesnake Bluff, and Baker's Bluff, is a reddish yellow, ferruginous sand, literally packed with the most beautifully preserved fossils. In many parts of Clarke and Monroe Counties, where this bed has undergone less change from exposure to the atmospheric agencies, these sands are mixed with a very considerable proportion of glauconite, and the color is a very decided dark green, instead of reddish yellow. This bed we have called the Claiborne Fossiliferous Sand. Below it are some 60 feet of calcareous clays and calcareous sands, the former making the upper 25 feet, characterized by a bluish color, shading into light gray below. The calcareous sands make up the lower 35 feet, and they are of a light yellowish color. The whole of this 60 feet of strata, except perhaps some 10 feet of blue clay near the top, is distinguished from all the other beds of the Claiborne formation by the great numbers of shells of *Ostrea sellæformis* Con. which it holds. These shells are found more abundantly in the hard, sandy ledges which occur at intervals of a few feet through the whole thickness of these beds. This part of the Claiborne formation, contrary to the experience of Professor Winchell,[2] we find to be the most widely distributed of any. We have identified it within two miles of Nicholson's Store in Choctaw County; at several localities on Souilpa Creek, in the same county; at Coffeeville; near Old Clarkesville; on Stave Creek; and near Lisbon Landing, in Clarke County; at Claiborne; near Monroeville; and at several places on Limestone Creek, in eastern Monroe County. It is described by Professor Hilgard[3] as occurring on Falling Creek, near Quitman, and on Suanlovey Creek, west of Enterprise, in Clarke County, in Mississippi, and it has been observed by Mr. Johnson in Wahtubba Cut, 5 miles

[1] Rep. on Geol. and Agric. of Mississippi, pp. 118, 119, 121, 122, 123, 124, 125, 1860.
[2] Proc. Am. Ass. Adv. Sci., Vol. X, Part II, p. 86, 1856.
[3] Rep. on Geol. and Agric. of Mississippi, pp. 126, 127, 1860.

southwest of Enterprise, Miss. We have not yet followed it further east than Evergreen, Conecuh County, though we have good reason for believing that it occurs near Elba, in Coffee County, and probably still further eastward. Below these *Ostrea sellæformis* beds we find at Claiborne and at Lisbon some 50 feet or more of sandy and clayey beds, in many cases strongly glauconitic, and holding a great number as well as a great variety of well preserved fossils.

Such are a few of the most obvious characters of the beds which we here wish to include in our Claiborne formation. The precise details of the structure and composition of these beds may be gathered from the sections which follow.

The rocks of the Claiborne formation proper occur at Claiborne, Gosport, and Rattlesnake Bluff, on the Alabama River, and at many other localities in that vicinity. They also occur on the Tombigbee River at Baker's Bluff (a short distance north of Saint Stephens) at Coffeeville and at very many points away from the rivers in Monroe, Clarke, Washington, and Choctaw Counties. We are at this time concerned only with the occurrences along the two rivers.

(*a*) The bluff at Claiborne affords one of the best exposures of the rocks of the Claiborne formation, as well as of part of the overlying Jackson strata, and we have therefore been at considerable pains to get a correct and detailed section of this celebrated bluff. It will be understood by every field geologist that no two observers will ever make the same grouping of the strata in a detailed section, and for this reason sections of the same bluff by different observers will often seem to be at variance with one another. The same bed, moreover, in different parts of a long bluff will often vary considerably in thickness and in other characteristics. Thus, along the road leading to the ferry at Claiborne, the ferruginous sands are less than ten feet in thickness and are overlaid with laminated clays holding leaf impressions, but these clays thin out rapidly going down the river and disappear altogether in less than a quarter of a mile from the ferry road. Our section, therefore, does not profess to be a section at one point only of the long Claiborne bluff, but we have examined and given the details of the different beds wherever they are most clearly exposed, from below the lower landing up to the ferry.

In this part of the State the Alabama River depression exhibits at least two well defined terraces; the upper one, from one hundred and seventy-five to two hundred feet above low water mark; the lower, from thirty to fifty feet above the same mark. The upper terrace is formed by the Tertiary rocks, which are, however, covered by thirty to forty feet of the sands and pebbles and loam of the drift. Upon this terrace, about a mile wide, the town of Claiborne stands. The second or lower terrace, in great measure above overflow, except in extremely high water, is formed of ancient river deposits to which the name "second bottom" has been given. Opposite Claiborne the second bottom is some three miles wide, and the river pursues its winding course in a channel cut into these second bottom deposits, impinging first against one side of the bordering Tertiary bluffs, whence it is deflected across the wide second bottom to strike then the opposite border. At Claiborne the river flows at the base of the southern Tertiary border of its ancient plain; next it turns across this plain and strikes the northern Tertiary bluff at Gosport; it is then deflected to strike the southern margin again at Rattlesnake Bluff.

The feature of the Claiborne bluff which first attracts the eye of the observer from a distance is the existence of nearly horizontal parallel stripes or bands which mark the limits of the different materials that make up the bluff. These bands, which are pretty well brought out in the views, are marked off approximately in the second vertical column of Plate XIII, Fig. 3, p. 147, and, if we neglect the minor details, they may be described as follows:

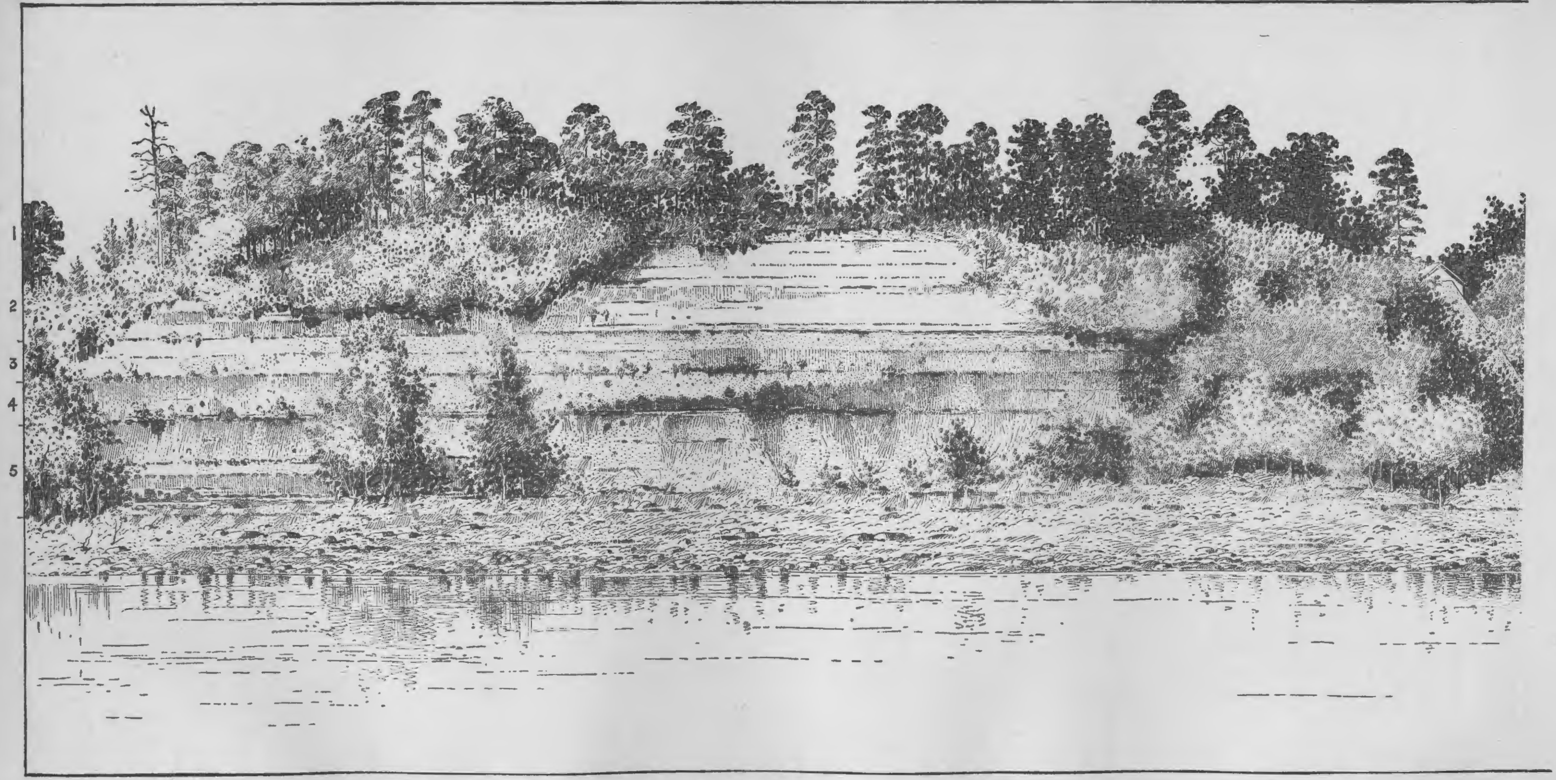
Section of the Claiborne Bluff, Alabama River.

1. A bed of very variable thickness, consisting of sand, pebbles, and red loam, which forms the surface over a great part of the State. The average thickness of this bed along the bluff may be put at ....35 to 40 feet.
2. A band of White Limestone containing glauconite grains, forming vertical faces usually striped by thin projecting ledges ....about 45 feet.
3. A band showing two very distinct parts, viz, an upper part, a bed holding great numbers of *Scutella Lyelli*, 3 feet thick; and a lower part, 6 feet thick, of coarse, ferruginous sands which are indurated at the base and form a very marked projecting ledge........................9 feet.
4. A band of very uniform appearance of reddish yellow or buff color, consisting of a mass of shells embedded in red sand. This is the celebrated Claiborne sand. It weathers very smoothly and is less projecting than the ledges above and below it ....15 to 17 feet.
5. A band of light gray, calcareous clay with a few sandy stripes and indurated ledges........................25 to 28 feet.

All these beds make up the nearly vertical part of the bluff near and between the two landings. Below these to the river level the slope is almost entirely covered by the loose fragments rolled down from above, so that the underlying stratified rocks are discovered only where these loose materials have been removed. Between the upper landing and the ferry these lower strata of the bluff are more clearly exposed to view.

6. A band of light yellowish gray, calcareous sand, striped with a number of hard ledges of similar sandy material. This band is a very prominent part of the bluff, but is in many places, as above stated, much obscured by the fragments of the other beds which have rolled down from above........................about 35 feet.
7. A band of dark, bluish green color, consisting of clayey sands and clays passing downwards into a greensand bed 6 to 8 feet thick, which appears, however, above water only above the upper landing ....about 12 feet.

The upper part of this band, at the lower landing, appears only two or three feet above the low water mark, and it is consequently best seen farther up the river. Between the two landings these beds, where they



1. Drift. 2. White limestone. 3. *Scutella* bed etc. 4. Fossiliferous sands. 5. *Ostrea sellæformis* beds.

CLAIBORNE BETWEEN UPPER AND LOWER LANDINGS, ALABAMA RIVER.

are above water, are generally covered with débris. The second of the bands above named is the lower part of the Zeuglodon bearing bed of this part of the State, which has generally been considered as of Jackson age. The third band is also probably a part of the Jackson limestone, but we are not sure that some of it, especially the lower five or six feet, should not be placed with the Claiborne division. At any rate the line between the Claiborne and the Jackson falls somewhere in this band (Plate I, p. 3, and Plate III, p. 29).

Given more in detail, the section of the Claiborne bluff is as follows:

Detailed section of Claiborne Bluff, Alabama River. (*Plate XIII, Fig.* 3, *p.* 147.)

1. Drift deposits, consisting of sand, pebbles, and red loam of variable thickness .... 35 to 40 feet.
2. Argillaceous, white limestone, with grains of glauconite, very few fossils .. 45 feet.
3. Scutella bed; light colored, calcareous materials, holding great numbers of *Scutella Lyelli* Con .... 3 feet.
4. Coarse, ferruginous sand, with glauconite, fossiliferous, passing below into more calcareous material, which is indurated and projects from face of bluff .... 6 feet
5. Ferruginous sand, holding vast numbers of comminuted as well as well preserved shells. Near the center of this there are, in places, thin bands of lignite, and along the ferry road the upper part of it is composed of laminated gray clays filled with leaf impressions. This is the source of the celebrated Claiborne fossils, and we shall call it the Claiborne Fossiliferous Sand. In many parts of Monroe and Clarke Counties, where this bed is more protected, the material in which the shells are embedded is seen to be a greensand, while at the Claiborne bluff and vicinity, and at a bluff just above Saint Stephens, it is completely oxidized into a red, ferruginous sand. Thickness about Claiborne .... 15 to 17 feet.
6. Bluish green, glauconitic, sandy marl, with *Ostrea sellæformis,* usually somewhat indurated above, and forming a hard projecting ledge .... 3 to 4 feet.
7. Calcareous clay or clayey marl, of gray color when dry, but blue when wet. It contains a few badly preserved chalky fossils, *Bulla* and small *Turritellas.* This bed becomes sandier below, as well as glauconitic and highly fossiliferous, the principal shells being *Ostrea sellæformis* and a few *Pectens.* The clayey and sandy parts, together .... about 18 feet.
8. Light gray, calcareous clay, similar to the upper part of the preceding bed, with hard sandy ledges at top and bottom .... 7 feet.
9. Light yellowish gray, calcareous sands, with *Ostrea sellæformis* and *Pectens;* the lower half indurated and full of the molds or casts of univalve shells ...... 5 feet.
10. Light yellowish gray, calcareous sands like those which make the upper half of bed No. 9. This bed has several hard projecting ledges of the same sandy material and contains a number of fossils: *Ostrea sellæformis,* fragments of *Scutella Lyelli, Scalpellum Eocense* Myer, *Pecten Deshayesii* Lea, &c. The sandy parts of this bed are loose, crumbling easily between the fingers. There are thin beds of more clayey texture, one of which, about the center of the stratum, holds a number of irregularly shaped, concretionary masses of clay. Near the base are one or two indurated ledges of glauconitic sand and shells of *Ostrea sellæformis* .. 27 feet.
11. Layer of comminuted shells of *Ostrea sellæformis,* together with perfect shells of some other species embedded in glauconite or greensand .... 3 feet.
12. Dark bluish black, sandy clay .... 2 feet.
13. Bluish green, clayey sands with few fossils in the upper part, but becoming more clayey below and highly fossiliferous; *Venericardia planicosta, V. rotunda, Nucula magnifica, Arca rhomboidella, Ostrea sellæformis, Voluta Sayana, Turritella lineata, T. bellifera* Aldrich, besides species of *Natica, Corbula, Cytherea, Lucina,* &c. This bed averages 10 feet or more in thickness.

14. Dark green, sandy marl, glauconitic; grayish above, bluish below. This bed is sometimes badly weathered and of more brownish color. It holds a number of fossils, among which the most noticeable are a peculiar small form of *Venericardia planicosta* Lam. and large *Turritella Mortoni* Con. This bed, which is the lowest at Claiborne, may be seen between the upper landing and the ferry, and its exposure is from six to eight feet, according to the stage of the water.

(*b*) A few miles above Claiborne, near Lisbon Landing, we find the continuation of the Claiborne beds down to the top of the Buhrstone, and there is no doubt as to the geologic horizon of the Lisbon section, since the two lowermost beds of the Claiborne section appear at the top of the Lisbon bluff, the peculiar association of the shells making the identification easy and certain. In the following full section at Lisbon the bracketed numbers show the relations of the Lisbon beds to those of Claiborne, as indicated in Plate XIII.

Section at Lisbon Bluff, Alabama River.

1. Drift and loam .... 20 feet.
2. [13] Brown, sandy clays, difficult to describe more closely, as they are badly weathered and contain very few fossils .... 10 feet.
3. [14] Dark brown, sandy clays, badly weathered, highly fossiliferous, containing the same shells as beds Nos. 13 and 14 at Claiborne, viz, the peculiar small variety of *Venericardia planiscosta* Lam., large *Turritella Mortoni* Con., *Arca rhomboidella* Lea, *Lucina compressa* Lea, *Nucula magnifica* Con., *Turritella bellifera* (Aldrich), &c. This bed becomes more sandy below .... 8 to 12 feet.
4. [15] Hard projecting sandy ledge .... 8 inches.
5. [16] Calcareous, clayey sands, light yellow when wet, nearly white when dry, glauconitic, forming smooth vertical bluff .... 6 to 8 feet.
6. [17] Coarse grained, sandy, glauconitic bed with comminuted shells and many finely preserved shells of uncommon occurrence .... 3 feet.
7. [18] Light yellow, glauconitic sands capped with hard ledge .... 15 feet.
8. [19] Blue, glauconitic sands, probably the same as No. 7 above, but less completely oxidized, lowest of Claiborne strata .... 5 feet.
9. Bluish black clay, 8 feet actually seen, below which, to the water, 5 feet, all the strata are covered by fragments of the concretionary sandstone described below.

In the clay immediately below the glauconitic sands, No. 8, concretionary masses are formed, which resemble a tangled mass of roots or branches, exposed in high relief upon a plate or block of sandstone. These root-like concretions lie strewn upon the lower strata of the bluffs about Lisbon, and seem to be somewhat characteristic of this particular horizon, which we place at the very summit of the Buhrstone division, the Claiborne proper extending to and including No. 8 [19] of the above section.

The combined sections of the Claiborne Bluff and the Lisbon Bluff show the whole of the Claiborne formation, which, according to our division, extends from the White Limestone down to the top of the Buhrstone and includes about 140 feet of strata, of which 106 are to be seen in place at Claiborne, while the rest may be seen a few miles above Claiborne at Lisbon.

The fossiliferous sands (No. 5 of Claiborne section) have furnished the greater part of the beautiful Claiborne shells. The uppermost five or six feet of this bed are made up chiefly of the shells of *Cytherea æquorea* Con., *Pectunculus Broderipii* Lea, and *Crassatella alta* Con., 90 per cent. of the shells belonging to the first named species. The two feet next below contain not only many of the Cythereas but great numbers of other shells also, the most prominent of which are *Turritella lineata* Lea, *Rostellaria velata* Con., *Crepidula lirata* Con., *Turbinella pyruloides* Con., *Voluta Defranckii* Lea, *Monoceros armigerus* Con., *Melongena alveata* Con., *Ancillaria subglobosa* Con., &c.[1]

The strata below the Claiborne sands are much less fossiliferous and more sandy, *Ostrea sellæformis* being by far the most abundant shell down to the black clay stratum near the base of the bluff. The greensand beds at the base of the Claiborne bluff and at the top of the Lisbon bluff contain many of the rarer forms. The marl bed No. 6 of the Lisbon section promises to yield a rich harvest of novelties.

The collocated sections on Plate XIII give the details of the preceding drawn to scale. For the sake of comparison we give on the same sheet the sections of Professor Tuomey[2] and of C. S. Hale.[3] Hale's No. 3 corresponds with our Nos. 14 and 15. His No. 4 and Tuomey's bed *b* are represented by our Nos. 12 and 13 and part perhaps of 11. Hale's beds 5 and 6 and Tuomey's *c* are our numbers 6 to 11, inclusive. The correspondence of the rest of the sections is easily seen.

Some of the more important exposures of the Claiborne beds elsewhere are the following:

(*c*) A few miles below Claiborne, at Gosport landing, there is substantially the same section as that at Claiborne.

(*d*) At Rattlesnake Bluff, below Gosport, there is the following section (see Plate XII, Fig. 4, p. 143):

Section at Rattlesnake Bluff, Alabama River.

1. Ferruginous sands, becoming more calcareous below and terminating with a hard ledge........6 feet.
2. Claiborne fossiliferous sands........10 to 12 feet.
3. Calcareous clay or hard clay marl, with an indurated ledge in the middle....6 feet.
4. Clay marl, with *Ostrea sellæformis*, with four or five hard, projecting ledges, about........10 feet.
5. Greensand, indurated at top but softer below, extending down to the water, about........2 feet.

(*e*) On the Tombigbee River, half a mile above Saint Stephens, there is a good exposure of the Claiborne sands, with some 10 to 12 feet of the next underlying beds, already given above in a section illustrating the White Limestone. (See Plate XII, Fig. 3, p. 143.)

[1] Aware of the fact that most of these shells have synonyms, we have in most cases given our authority for the names used by us, leaving the question of priority to be decided hereafter.

[2] First Bien. Rep. Geol. Ala., p. 153, 1850.

[3] Geology of South Alabama, Am. Jour. Sci., 2d ser., Vol. VI, p. 354, Nov., 1848.

(*f*) Still farther up the river, at Coffeeville landing, the *Ostrea sellæformis* beds of the Claiborne profile form the river bluff, as may be seen from the following:

Section at Coffeeville Landing, Tombigbee River. (*Plate XIII, Fig. 4, p.* 147.)

1. Light yellowish sands, with *Ostrea sellæformis*, partly indurated, forming sandy ledge .... 3 feet.
2. Loose, yellowish, calcareous sands, with *Ostrea sellæformis*, indurated, sandy ledge at base .... 6 feet.
3. Loose, yellowish gray, calcareous sands, highly fossiliferous, especially in lower part; *Ostrea sellæformis* the principal form; separated from next bed by sandy ledge .... 10 feet.
4. Bluish, sandy clay or clayey sand, with *Ostrea sellæformis* and a flabellum; in two parts, separated by a hard ledge, the upper part 8 feet, the lower 3 or 4 feet, in all .... 12 feet.
5. A bed of glauconitic sand filled with shell fragments and perfect shells: *Ostrea sellæformis* Con., *Crassatella alta* Con., a flabellum, *Venericardia rotunda* Lea, *Corbula Murchisoni* Lea, *Pecten Deshayesii* Lea, *Arca rhomboidella* Lea, *Nucula magnifica* Con., &c .... 2 to 3 feet.
6. Dark bluish clays, nearly black, non-fossiliferous, breaking into cuboidal blocks .... 2 feet.
7. Dark greenish, clayey sand, like that near the base of the Claiborne Bluff, about 5 feet showing above the water.

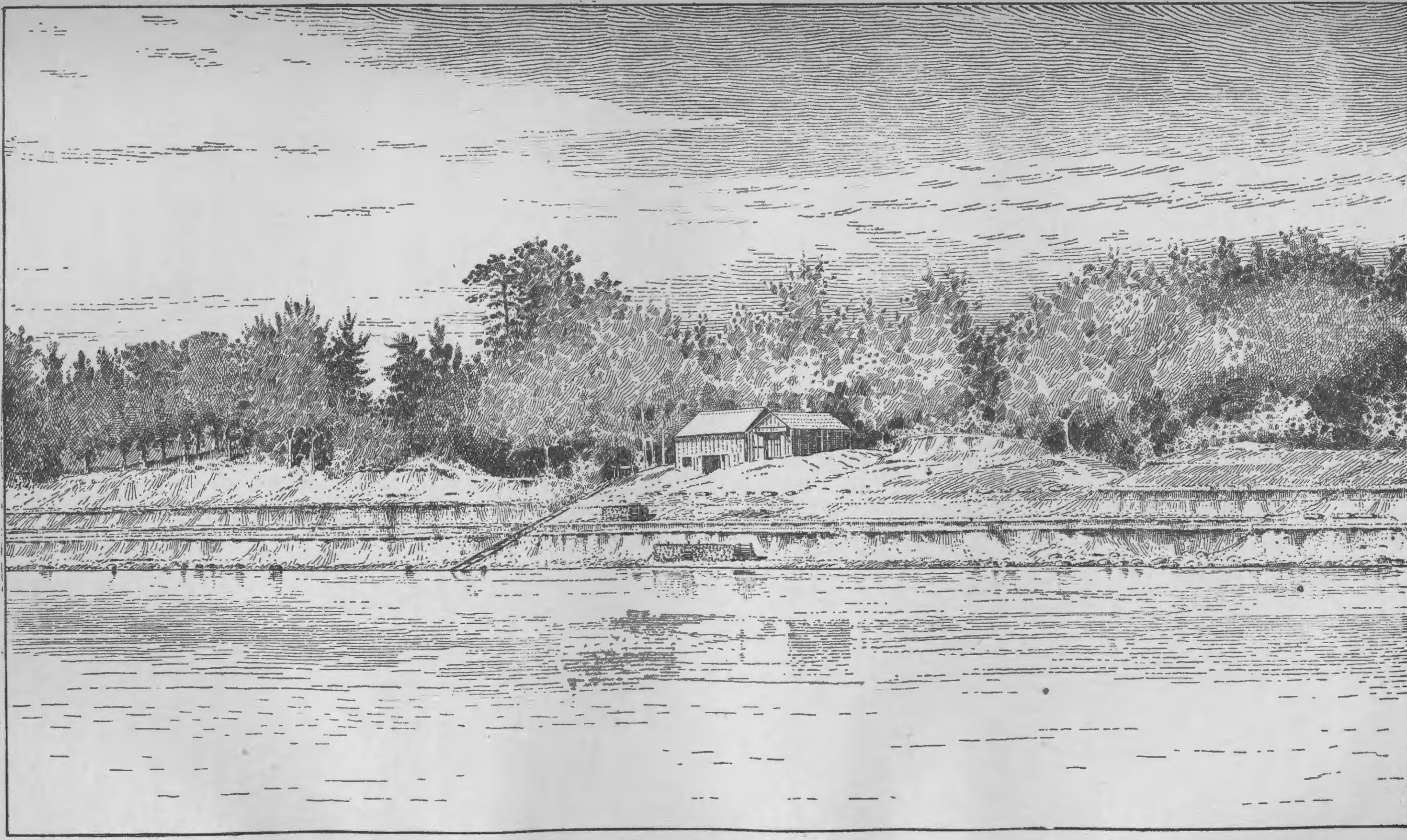
The accompanying view of Coffeeville Landing (Plate IV) shows well the general character of the lower Claiborne beds. The lowest wood piles rest upon the black clays, No. 6, equivalent to No. 12 of the Claiborne Bluff section. The main fossil bearing bed, No. 5, is immediately over this, between it and the first (lowest) of the projecting ledges seen in the plate.

Hale states[1] that his bed No. 4 occurs also at Coffeeville with the same fossiliferous characters, and a comparison of the Claiborne Bluff section with the above shows very clearly the correspondence of the two. The bed No. 5 above is identical with No. 11 at Claiborne, except that it holds *Crassatella alta* and a few forms which we have not seen at the same horizon at Claiborne; but the underlying black clay (No. 6) is equivalent to No. 12, and the overlying bluish and yellowish, fossiliferous sands (Nos. 1–4) are identical with Nos. 9 and 10 of our Claiborne Bluff section. These relations are shown in the sections, Plates XII and XIII.

There are no other exposures of the Claiborne beds along the two rivers, but in Washington, Clarke, and Monroe Counties we have recently (summer of 1885) visited a number of localities where the Claiborne beds are to be seen often in contact with the overlying White Limestone.

(*g*) Thus, north of Bladen Springs, on descending the hill towards Souilpa Creek, yellowish sands, with *Ostrea sellæformis*, the counterpart of our Nos. 9 and 10, are passed over along the road, while above them, near the top of the hill, is a fossiliferous bed holding forms common both to the Claiborne sands and to the marls at the base of the Claiborne Bluff.

[1] Am. Jour. Sci., 2d ser., Vol. VI, Nov., 1848.



COFFEEVILLE LANDING, TOMBIGBEE RIVER.

(*h*) At the Barryton mill on Oaktuppah Creek, three miles northeast of the village of Barryton, there is a bed of greensand filled with broken and perfect shells of *Ostrea sellæformis*, identical with No. 11 of our Claiborne Bluff section, and above it, as at Claiborne, a series of bluish and yellowish sands, with *Ostrea sellæformis*.

(*i*) About two miles northward from this mill the Claiborne fossiliferous sands occur, and at Womack's Hill, still farther northward, the White Limestone caps the hill.

(*j*) The yellow sands, with *Ostrea sellæformis*, are also seen at a mill on the headwaters of Oaktuppah Creek, in the western part of Choctaw County, Sec. 8, T. 11 N., R. 4 W., and again within two miles of Nicholson's Store, on Billy's Creek, where they are exposed at the base of a hill capped with the White Limestone.

(*k*) Thirteen miles west of Bladen Springs, D. W. Langdon, jr., of the Geological Survey of Alabama, saw in 1884 an outcrop of greenish, argillaceous sand, weathering red and containing a number of shells peculiar to the Claiborne sands, such as *Crepidula lirata*, *Corbula Alabamensis* Lea, and others commonly found in the Claiborne sand but not peculiar to it. This bed also was beneath the White Limestone.

(*l*) In the northern part of Washington County I saw, in 1882, an outcrop of marl containing *Turritella Mortoni* Con., *Ostrea sellæformis* Con., *Voluta Sayana* Con., &c., on Dry Creek, Sec. 6, T. 8, R. 2 W.

(*m*) In Clarke County, near the site of Old Clarkesville, in Sec. 23, T. 9 N., R. 2 E., there is seen in the bed of a branch a greensand containing all the peculiar shells of the Claiborne fossiliferous sands, and on the hills above White Limestone containing bones of Zeuglodon.

(*n*) In Sec. 18, T. 9 N., R. 3 E., the same beds occur, and in the same relations to the White Limestone.

(*o*) On Stave Creek, in Secs. 8 and 9 of T. 7 N., R. 2 E., and in other localities in the immediate vicinity, the Claiborne sands, with all their easily recognizable and unmistakable shells, are at the water level in the creek banks, while the White Limestone outcrops on the hillsides hard by, with orbitoidal limestone on the summits.

(*p*) D. W. Langdon, in 1884, observed the Claiborne sands also nine and a half miles south of west of Grove Hill and fifteen miles east of Coffeeville, in both cases underlying the White Limestone. The locality on Stave Creek was visited by Prof. A. Winchell[1] and the localities near old Clarkesville were seen by Professor Tuomey[2] and by Professor Winchell[3] also.

(*q*) In Monroe County the yellow sands, with *Ostrea sellæformis*, occur in sections 25 and 34 of T. 7 N., R. 8 E., and in sections 19 and 30 of T. 7 N., R. 9 E., partly on the land of Mr. T. A. Rumbly.

[1] Proc. Am. Assoc. Adv. Sci., Vol. X, Part II, pp. 84, 85, 1856.

[2] First Bien. Rep. Geol. Alabama, p. 149.

[3] Proc. Am. Assoc. Adv. Sci., Vol. X, Part II, p. 86, 1856.

(r) In Sec. 2, T. 7 N., R. 7 E., occur the yellow sands, with *Ostrea sellæformis*, as at Rumbly's, and in Sec. 12, T. 7 N., R. 7 E., the Claiborne greensand, with all the characteristic shells, occurs in the branches of the creeks, while the White Limestone occupies the summits of the hills.

Our observations correct a statement of Professor Winchell[1] that the calcareous beds underlying the Claiborne sands are not seen elsewhere. These beds are now known to occur from the western part of Choctaw to the Sepulga River, in Conecuh County, and probably still farther eastward.[2]

Other occurrences of the Claiborne beds, observed in 1886, will be found described below in the chapter on undulations &c.

§3. THE BUHRSTONE.

The fossils of this subdivision, as has already been suggested by Dr. Hilgard, do not appear to differ essentially from those of the calcareous Claiborne strata above described, yet the lithological character is so entirely different as fully to justify the division here made.

The rocks of the Buhrstone formation in Alabama, as well as in Mississippi, consist of aluminous and silicious materials, partly glauconitic, and in places interstratified with thin beds of greensand. The chief varieties of these rocks, in the order of their relative abundance, are the following:

1. Gray, aluminous sandstone, often glauconitic, with numerous galls or concretions of pure whitish clay and traversed throughout with streaks of yellowish, hydrated oxide of iron. In this rock are occasionally found impressions of shells. In the upper part of the formation, upon the surfaces of this sandstone irregularly branching, cylindrical elevations of slightly harder texture, but apparently of similar composition, are sometimes seen. These ridges have in some cases the appearance of being organic remains (fucoidal), but are more probably concretionary. These are best seen at Lisbon Landing on the Alabama River, and west of Bladen Springs, in Choctaw County, and at other points along the southern line of this formation.

2. Indurated, white clay, forming a rock, which is, however, quite light and easily broken. This indurated clay has joint planes approximately at right angles to one another, the planes of separation being mostly stained red or yellow with hydrated ferric oxide. Fragments of this claystone worn into rounded pebbles are of common occurrence in most of the creeks and branches flowing through the Buhrstone hills both in Alabama and in Mississippi. The claystones are often silicious.

3. Hard, coarse grained, glauconitic sandstone.

4. Hard, yellowish, silicious, or aluminous sandstone, streaked with a darker shade of yellow.

5. A white, silicious rock, almost a quartzite, varied by spots of leaden gray color. This rock has often furnished the material for Indian lance and arrow heads. It occurs near the base of the series, associated with a hard, silicious sandstone.

The prevailing color of the rocks of this formation is light gray, often nearly white, and, on account of their hardness and resistance to decay,

[1] Proc. Am. Assoc. Adv. Sci., Vol. X, Part II, page 86, 1856.

[2] D. W. Langdon, jr., has also traced these sandy *Ostrea sellæformis* beds into Mississippi, as far as Suanlovey Creek, near Garlandsville, in Newton County, a locality already recorded by Dr. Hilgard. See paper "On the Tertiaries of Mississippi and Alabama," in Am. Jour. Sci., 3d ser., Vol. XXXI, Mar., 1886. See, also, pp. 25–33 and foot-notes.

the country which they make is very broken and rugged. The high and often precipitous hills of the Buhrstone are usually called *mountains* in Clarke, Monroe, and Choctaw Counties, in this State, and in northeastern Clarke, Lauderdale, Newton, and Neshoba Counties, in Mississippi. The soil, where it is derived from these rocks, is, of course, poor, and mostly timbered with long leaf pine, and the country is generally very sparsely settled.

It is impossible as yet to give with absolute certainty the thickness of this division of the Tertiary. During the summer of 1885, I measured with the aneroid barometer at one locality, near McCarthy's Ferry, in Choctaw County, 270 feet of Buhrstone rocks, and, as this section did not include the uppermost beds of the formation, we are safe in placing 300 feet as the minimum thickness. I am strongly inclined to the opinion that the real thickness, in some cases, will rise to 400 feet. In the section we give the lower limit, 300 feet.

In general, the uppermost beds (fifteen to twenty feet) are composed of joint clays, which, when indurated, form tolerably firm rocks. Near the base of the formation similar clays or claystones are usually seen. In many places, there is a bed several feet in thickness of a hard, silicious, or flinty sandstone, almost a quartzite, just at the base of the Buhrstone. I have noticed this rock a few miles north of Bladen Springs, also near McCarthy's Ferry, and south of Pushmataha, in Choctaw County. In Choctaw and Clarke Counties it is not unusual to find spear or arrow heads made of this material, which is easily recognized. The great bulk of the Buhrstone, as already said above, consists of aluminous sandstones.

Inasmuch as we have not yet been able to point out any characteristic distinction, based upon organic remains, between the Buhrstone and the Lignitic, we have thought it best to draw the line between them upon lithologic grounds, and our justification in this course is found in the following considerations: In the strata which we have called Lignitic, the material, as compared with that of the Buhrstone, is more sandy and calcareous and at the same time more fossiliferous. The shells in many cases are decayed and the calcareous matter of the same often appears to have been leached out and diffused through the surrounding sands, occasionally cementing them together and forming calcareous sandstone. These sandstone beds always show a tendency to weather into rounded, bowlder-like masses, which project from the faces of the bluffs or, broken off, roll down, forming a talus. When broken open, these bowlders usually show a nucleus of thoroughly decayed shells or of ferruginous, lignitic matter.

A ledge of calcareous sandstone of this kind is found about twenty or thirty feet below the lowermost of the aluminous rocks, which we consider as characteristic of the Buhrstone, and similar calcareous sandstones weathering into bowlders occur at intervals throughout the underlying lignitic strata.

The aluminous rocks we assign to the Buhrstone, while the sandy rocks, with the intercalated beds of calcareous matter, we place with the Lignitic.

This division based upon lithologic characters can be consistently carried out in Alabama, at least in the region contiguous to the two rivers, since the indurated clays and aluminous sandstones of the Buhrstone are in general easily distinguished from any of the other strata of the Tertiary formation. None of the beds of the underlying Lignitic have even a remote resemblance to the Buhrstone rocks, except certain indurated clays which overlie the *Gryphæa thirsæ* beds in the Grampian Hills of Wilcox County and their prolongation into Butler County. Even in this case the distinction between the two can readily be discovered, as the indurated clays of the Lignitic are, in some of the beds, quite full of shell casts, principally Turritellas and Cythereas, and the material itself, upon close examination, does not so strongly resemble the Buhrstone as upon first sight appears. Then the circumstances that these lignitic claystones lie over 300 feet below the Buhrstone, are by no means so thick, and are in most, if not all, cases in immediate contact with the *Gryphæa thirsæ* beds greatly diminish the chance of any confusion between the two series.

On the Alabama River the uppermost of the Buhrstone beds are well exposed at Lisbon Landing, and the lowermost, a short distance above Hamilton's, whence they extend across Clarke County westward or northwestward to White Bluff and McCarthy's Ferry and thence in a northwesterly direction across Choctaw County, just south of Butler. On the eastern side of the Alabama River they appear in the hills south of Bell's Landing, and across Monroe County north of Kempsville and south of Turnbull, turning a little to the northward in the eastern part of the county. To the eastward they may be seen again near Ozark, in Dale County, and near Abbeville, in Henry County.

In general we have not attempted in the following sections to give the exact sequence of the different materials which form the Buhrstone beds. In most cases they are merely alternations of indurated clays, with aluminous sandstones of varying degrees of hardness. While in the extremes of pure clay and almost pure quartz the materials of this formation differ widely, the formation as a whole leaves upon the mind of the observer a lively impression of the uniformity in the lithological structure and general appearance of its constituent strata.

Although the best natural sections of the Buhrstone are perhaps to be found in the hills away from the rivers, we shall here describe only the exposures along the banks or in the immediate vicinity of the two water courses. The sections on the Alabama River are as follows:

(*a*) *Section at Lisbon Landing, Alabama River.* (*Plate XIV, Fig.* 1, *p.* 151.)

1. Yellowish, sandy marl, lowermost of the Claiborne beds.................. 20 feet.
2. Bluish black clay, massive, jointed or breaking into cuboidal blocks, 8 feet seen, but to the water's edge.......................................about 15 to 20 feet.

Immediately beneath the sands which form the lowermost beds of the Claiborne formation in this section concretions are formed which resemble a mass of tangled and matted roots. Blocks of sandstone with these concretions cover all the lower part of the section at Lisbon and they seem to be more or less characteristic of the uppermost beds of the Buhrstone.

(*b*) At Hamilton's Landing, 6 miles above Lisbon, is an exposure of 75 to 80 feet of light colored, indurated clays or clayey sandstones with two or three indurated, projecting ledges, all characteristic Buhrstone rocks. (See Plate XIV, Fig. 2, p. 151.)

The positions of the outcrops of the Buhrstone rocks on the Tombigbee River present apparent anomalies which, at the time of our visit in 1883, we could not explain. The later observations, however, made by myself in 1885 have cleared up many of the obscurities, and the structure of the two counties of Clarke and Choctaw in its main features is pretty definitely made out. This will be set forth in detail in a forthcoming report of the Geological Survey of Alabama, while at this time we need only give the sections exposed on the river banks and in the immediate vicinity. As stated above, the regular line of outcrop of the Buhrstone rocks extends from near Hamilton's Landing, on the Alabama, across to the Tombigbee at White Bluff and McCarthy's Ferry. At both these localities we have very good sections of the lower beds of the formation.

(*c*) At White Bluff there is a clear exposure of these rocks in a cliff of about 115 feet. They are light colored, aluminous rocks, which, however, could not be closely examined because of the precipitous nature of the bluff. (See Plate XIV, Fig. 4, p. 151.)

(*d*) At McCarthy's Ferry the immediate bluff of the river is made of the clays which underlie the Buhrstone, but on the hills just back of the river we get a section of nearly 300 feet of Buhrstone rocks. (See Plate XIV, Fig. 3, p. 151.)

(*e*) Down the river from these localities the Buhrstone rocks dip beneath the surface, the overlying Claiborne beds forming the river banks, as at Coffeeville, &c., already mentioned, but just south of Coffeeville, at Hatchetigbee Bluff, the Buhrstone is again seen, and the lowermost beds at that, as shown in the section (see Plate XIV, Fig. 5, p. 151). The exposures at White Bluff and at the Hatchetigbee Bluff both show the contact of the light colored claystones with the underlying sandy clays &c. of the Lignitic, but at the former locality all except the uppermost 20 feet or so of the Lignitic are obscured by land slips and rubbish of all sorts. These sections will be given in detail under the next heading.

(*f*) Still farther down the Tombigbee River these rocks sink again below the surface, for at Saint Stephens, and just above, the Claiborne sands and the overlying White Limestone make the river bluffs, as before stated. At the Lower Salt Works, however, we have the Buhrstone rising again to the surface, as described by Professor Tuomey.[1] During the summer of 1885 I ascertained that these rocks appear at the surface at an intermediate point, viz, near Jackson. The Lower Salt Works are situated near the center of T. 5 N., R. 2 E., and the rocks exposed along the road which ascends the hill just south of the works are as follows:

Section at the Lower Salt Works, Clarke County.

1. Orbitoidal limestone forming the upper part of the hill, thickness not determined.
2. Between the orbitoidal rock and the topmost bed of the continuous section below given there is a space in which the rocks are covered with soil, undetermined thickness.
3. Argillaceous White Limestone or clayey marl, with several indurated ledges of similar material .... about 18 to 20 feet.
4. Coarse grained, ferruginous sand, with harder ledge at base and above. This bed, as well as the harder portions, contains fossils, the most conspicuous of which are *Scutella Lyelli* and *Pecten perplanus*. This bed is strongly glauconitic near the base .... about 9 feet.
5. Greenish clay passing at bottom into a ledge of hard claystone, the first of the Buhrstone formation .... 3 feet.
6. Aluminous sandstones or indurated claystones of the usual Buhrstone character to the base of the hill .... 60 feet or more.

About half way down the hill there is a bed of greensand holding a good many fossils.

That which most strikes the observer in this section is the absence of the sands and marls of the Claiborne formation. The glauconitic sands with *Scutella Lyelli* and *Pecten perplanus*, supposed to be of Jackson age, immediately overlie the greenish clays of the Buhrstone, while at Claiborne the two are separated by at least 130 or 140 feet of other strata.

Professor Tuomey[1] called attention to the fact that the Buhrstone beds, after dipping beneath the surface in the upper part of Clarke County, appear again at the Lower Salt Works, the White Limestone and other calcareous strata occupying a basin in the Buhrstone formation. Our own observations on the river in 1883, and later in 1885 in the western part of Clarke County and in Choctaw County, have shown that the Buhrstone rocks appear at at least two intermediate points between the two limits observed by Professor Tuomey, viz, at Hatchetigbee and at Jackson.

§ 4. THE LIGNITIC.

All the strata lying between the Buhrstone and the Cretaceous, representing a thickness of 850 to 900 feet, have been classed by Dr. Hilgard under the two names of Lagrange (or Lignitic) and Flatwoods. Lately, Prof. Angelo Heilprin has proposed the name Eolignitic for both these divisions; but, since Dr. Hilgard had already used the name Lignitic in the same sense, that term has priority and must be retained.

[1] First Bien. Rep. Geol. Ala., p. 150, 1850.

The greater part of this subdivision is made up of laminated clays and laminated and cross bedded sands of a prevailing gray color, except immediately below the Buhrstone, where for 200 feet or more they are of dark brown, often purplish colors. With the above mentioned laminated clays and sands are interstratified several beds of lignite and several beds holding marine fossils and usually characterized by the presence of glauconite or greensand.

The lignite beds appear to be more numerous and thicker towards the west, and especially in Mississippi, while eastward of the Alabama River they become, as a rule, inconspicuous. Only one of these lignites, viz, that which appears at Coal Bluff, on the Alabama River, is of very considerable size, six or seven feet; they possess no very well marked characters by which they may be distinguished from one another; they are traced with difficulty across the country, since, being softer, they are more easily eroded than the associated rocks. On the other hand we have found the marine beds to retain their characteristic features to a remarkable degree: each has its peculiar association of fossils, most of them are also easily recognizable by lithologic and structural characters, and some of them may be followed with the greatest ease across at least three counties. These circumstances have led us to use the marine beds instead of the lignites for marking the different horizons of the Lignitic division, and provisionally we have thus used the seven following marls, each marking a well defined horizon and each presenting its easily recognized paleontologic character:

1. The Hatchetigbee marls.
2. The Wood's Bluff or Bashi marl.
3. The Bell's Landing series.
4. The Nanafalia or *Gryphæa thirsæ* marl.
5. The Matthews's Landing and Naheola marls.
6. The Black Bluff beds.
7. The Midway or Pine Barren beds.

Our account of the stratigraphy of the Lignitic division of the Alabama Tertiary will be more intelligible and more easily followed if we describe the strata in sections, each corresponding to and including one of the seven marl beds above enumerated.

(1) THE HATCHETIGBEE SERIES. (PLATE XV.)

In this we would include all the strata intervening between the base of the Buhrstone and the uppermost of the Wood's Bluff fossiliferous beds, aggregating about 170 to 175 feet, as may be seen by consulting the engraved sections of Plate XV, especially Fig. 1, p. 155.

By far the greater part of the beds here included are sandy clays or clayey sands of brownish gray colors, alternating with bands of dark brown or purple color, the whole forming a tolerably well marked and in most cases easily recognized group. Where these brown clays have been much exposed to the action of the atmosphere, and consequently thoroughly leached, as occurs wherever they lie high up on the hills, they exhibit very much lighter and less characteristic colors. The best exposures of these beds are to be seen at the localities more particularly described below, and at one of them, White Bluff and vicinity, the whole series occurs in actual superposition, only about sixty-five feet of it being somewhat obscured by slides. The distinctively marine deposits of this series consist of three or four shell or marl beds, separated by non-fossiliferous sands and clays (Plate V).

(*a*) *Section at Hatchetigbee, Tombigbee River.* (*Plate XV, Fig. 2, p. 155.*)

1. Light colored, aluminous sandstones and indurated clays, forming a vertical escarpment back of the main bluff .... 20 to 30 feet.
   These light colored claystones we consider to be the lowermost of the Buhrstone formation, and all the underlying to be Lignitic.
2. Sandy clays of brown, yellowish, and reddish colors interstratified. These are dark blue when moist, but of lighter colors when dry .... 15 to 20 feet.
3. Heavy bedded, dark brown clays, somewhat like No. 2, but of darker color when dry .... 10 feet.
4. Yellowish, glauconitic marl .... 2 to 3 feet.
   This bed shows a tendency to form at intervals hard concretionary ledges, which on weathering break off and roll down the bluff and are piled in great numbers at its base.[1] Some of these bowlders have a nucleus of shells, which, however, are not usually very well preserved.
5. Purplish brown, sandy clays, in the middle of which is a projecting ledge of dark colored clays which are harder but break up into small prismatic fragments upon drying and on exposure to weather .... 15 feet.
6. Yellowish gray sands, striped with thin streaks of brown, sandy clay. These sands form, at intervals along the bluff, indurated, concretionary, rounded masses .... 5 to 6 feet.
7. Bluish brown, sandy, clay marl, containing many new forms of shells. The upper part more fossiliferous .... 5 to 6 feet.
8. Laminated, grayish sands, interstratified with thin beds of brown or black, lignitic clay. These sands form rounded, concretionary masses, which project from face of bluff .... 4 feet.
9. Heavy bedded, gray, sandy clays with streaks of brown clay .... 8 feet.
10. Reddish, sandy marl, highly fossiliferous, forming concretionary bowlders. Remarkable for the great numbers of *Venericardia planicosta* Lam., but containing also many other forms, such as *Athleta Tuomeyi* Con., and *Fusus pagodiformis* Heilprin .... 4 to 5 feet.
11. Dark gray to brown sandy clays to water .... 15 feet.

Beds No. 8 and 9 above form very conspicuous parts of the bluff, as they are striped with dark brown, nearly black, bands of clay and resemble strongly a part of the section at McCarthy's Bluff described below.

[1] Between our joint visit in 1883 and my second in 1885 the appearance of the bluff was very materially changed by a landslide. In 1883 we saw about six feet below the marl bed No. 4 another of very similar character, which I have now reason to think was a mere repetition of No. 4, since I was unable to make out two such beds in 1885. I have, therefore, given only one in the section, though convinced of the existence of two at the time of our first visit.

5. Lower part of purplish brown, sandy clays. 6. Yellowish gray sands. 7. Bluish brown, sandy marl.

(The human figure stands upon the bed which we call the middle marl. References are to the sections on p. 40, and also to Fig. 2 of Plate XV.)

HATCHETIGBEE—UPPER END OF BLUFF, TOMBIGBEE RIVER.

(*b*) At White Bluff, on the Tombigbee, as above stated, there is another exposure of the contact between the Buhrstone and the underlying Lignitic, which, however, includes in continuous exposure only the uppermost 25 feet of the latter formation. From the top of White Bluff down to the river level the distance is 275 feet by barometric measurements made at several different times. Of this, the uppermost 140 feet are shown in a clear perpendicular bluff and consist of 115 feet of the light colored claystones of the Buhrstone formation and 25 feet of sandy clays of the Lignitic. The strata composing the rest of the slope of White Bluff are so much obscured by landslides that it is impossible to make them out satisfactorily, but the lowermost 70 feet of the beds which make this slope are well exposed on the banks of Witch Creek and at Davis's Bluff, near by. Between these two parts of the section there are some 65 feet of strata not seen here, which include the Hatchetigbee marls &c. In proof of this, I found on the slope, a few feet below bed No. 3 of the accompanying section, a fragment of hardened, glauconitic marl with a few badly preserved fossils. The marl resembled that described in No. 4 of the Hatchetigbee section above. The fossils were, however, too obscure to be identified.

All this is shown in the following section and in Plate XV, Fig. 1, p. 155:

Section at White Bluff and Davis's Bluff, Tombigbee River.

1. Aluminous sandstones and claystones, of light color, forming a vertical bluff, the details of which it is impossible to examine closely, Buhrstone rocks....115 feet.
2. Grayish, sandy clays, with a layer about 18 inches in thickness at its base, containing fragments of lignitized stems and twigs........................20 feet.
3. Sandy clays, with a layer at bottom about 8 inches thick, consisting of alternating layers (one-fourth of an inch in thickness) of lignite and sand........5 feet.
4. Strata not seen, covered by landslides[1]................................ 65 feet.
5. Gray, sandy clays, striped with brownish purple bands of clay, containing few if any fossils, except that about 12 feet above the water there occurs a thin bed with a few fossil shells, and some 12 feet above this a single specimen of *Athleta Tuomeyi* was found sticking in the clay[2]...70 feet.

White Bluff is in the southwestern part of Sec. 14, T. 11 N., R. 1 W., just below the mouth of Witch Creek.

(*c*) Above this, the river bends towards the west, and in the northwestern part of Sec. 6, T. 11 N., R. 1. W., at McCarthy's Ferry, the strata which make the lower part of the preceding section are again exposed, as may be seen from the following section:

Section at McCarthy's Ferry, Tombigbee River. (*Plate XV, Fig.* 3, *p.* 155.)

1. Sandy clays interlaminated with clays less sandy, all of light gray colors, but along the whole length of the bluff there are parallel bands of much darker clays, which make a very conspicuous marking ....50 to 55 feet.

[1] A fragment of glauconitic sandstone with fossils was picked up from the surface in this part of the section a few feet below the base of No. 3.

[2] These beds, as well as those included in No. 4, are covered by the débris of landslides at White Bluff, but they are well shown in the banks of Witch Creek, which washes the base of White Bluff, and at Davis's Bluff, half a mile above, where we get the lower 70 feet of the section (No. 5).

2. Laminated clays and sands, firm and compact at base, forming a projecting ledge which divides the bluff into two parts. .... 4 to 5 feet.
3. Pyritous, sandy clays, with two or three bands of darker color; the sands are indurated in places, forming bowlder-like masses .... 20 to 25 feet.

The dark bands which mark the bluff and which look at a distance like lignite beds are found upon closer inspection to consist of thin layers of dark bluish gray clays interbedded with thin streaks of gray sand. The whole 75 feet of this section appear to be barren of fossils.

At the base of the bluff lie great numbers of fragments of the silicious and aluminous rocks which characterize the Buhrstone formation and which have rolled down from the hills that rise a short distance back of the immediate bluff of the river. These hills are composed entirely of the Buhrstone rocks for a vertical distance of 270 feet. (See Plate XIV, Fig. 3, p. 151.) This is the greatest thickness of Buhrstone rocks that has been measured in one section, except at one other place in the same range of hills.

Above McCarthy's Bluff I failed to find any outcrop of the Hatchetigbee marls, but a short distance northward, on the road to Mount Sterling, some 10 to 11 miles south of Butler, the road descends over 250 feet of Buhrstone rocks, below which I saw in 1885 an indurated greensand marl with fossils embedded in brown sandy clays. This is doubtless one of the Hatchetigbee marls.

The position of the McCarthy's Bluff beds with reference to the Buhrstone and to the Davis's Bluff beds is shown on the general section in Plate XIV, Fig. 3 (p. 151), and in Plate XV, Fig. 3 (p. 155).

Up the Tombigbee River from White Bluff and Davis's Bluff to Wood's Bluff, similar dark gray, sandy clays with darker bands are displayed in the river banks. The thickness of the strata between the Buhrstone and the top of the Wood's Bluff marl is about 175 feet, of which the lower 100 feet are well characterized by a prevailing dark brown or slightly purple color and by the absence of fossils, except an occasional band of lignitic clay or a sandier band with a few marine shells. The upper 75 feet are more fossiliferous and varied in appearance.

In these lower, dark, sandy clays there occur concretionary masses of silicious matter, sometimes almost a flint of approximately spherical shape, and made up of concentric layers or shells. These concentric shells are usually separated by a thin layer of pure quartz of fibrous texture, the fibers being perpendicular to the surfaces of the spheres. These concretions are very commonly looked upon as petrified turtles by the people of the vicinity. They vary from 6 inches to 4 or 5 feet in diameter. In other places the clayey sands themselves are cemented together into rounded concretions, with a nucleus of black lignitic matter.

Where the dark brown or purple, clayey sands above described occur at considerable elevations above the water and have been thoroughly leached and desiccated, they exhibit very much lighter colors. They are seen under such condition on the hills back of Yellow Bluff, on the Alabama River, and in the country between the two rivers. It is only along the river bluffs and low places, where they are kept more or less moist, that the dark purple and brown shades are so characteristically displayed.

(2) THE WOOD'S BLUFF OR BASHI SERIES. (PLATES XV AND XVI.)

The first beds of marine fossils of any consequence below the series of brown and purple clays above mentioned occur at Wood's Bluff, on the Tombigbee, and just below Johnson's Island, on the Alabama River; also, on Bashi Creek and its tributaries in Clarke County, and at numerous other localities to be given below. We have given to these beds the name of the *Wood's Bluff* or *Bashi Marl.* They are from 15 to 20 feet in thickness, are highly fossiliferous, hold a very considerable percentage of greensand, and the marl has a tendency to become indurated by carbonate of lime into rounded, bowlder-like masses of glauconitic, fossiliferous limestone. These bowlders may be formed in any part of the beds, but are more commonly seen in the upper half, and when this is the case the loose greensand marl below is easily washed out, giving rise to the formation of caves, sometimes of considerable dimensions. Immediately below this marl, and usually within 25 feet of it, are at least four or five thin seams of lignite, varying from a few inches up to 18 inches in thickness.

All these characters render the Wood's Bluff marl easily recognized, and it has been traced by me from the western part of Choctaw across to the eastern part of Monroe County without any essential change in its quality. It has become one of our most important geologic landmarks.

Some 35 to 40 feet below the lowermost of the thin, lignitic beds immediately underlying the Wood's Bluff marl, and separated from it by yellowish, cross bedded sands, is another lignite, about two feet in thickness, at the base of which we wish to draw the line between the Wood's Bluff and the Bell's Landing series. As thus defined, the Wood's Bluff series includes the strata intervening between the purplish brown, sandy clays, above described, immediately overlying the Wood's Bluff marl, and the two feet of lignite. The thickness represented is about 80 feet. The most complete section of the whole series is at Yellow Bluff, on the Alabama River. (See Plate XVI, Fig. 1, p. 159.)

The best exposures of the marl bed are to be seen at Wood's Bluff, on the Tombigbee River, and on the tributaries of Bashi Creek in Clarke County, in the immediate vicinity of Wood's Bluff, although, as stated above, the marl may be readily traced across Choctaw, Clarke, and Monroe Counties, exhibiting at many places away from the rivers very fair sections. On the immediate banks of the Alabama River the marl does not make much show, though it may be seen below Johnson's wood yard.

We give here only three sections, showing the details of the marl bed and of the strata underlying down to the top of the next, or Bell's Landing, series.

(*a*) *Section at Wood's Bluff, Tombigbee River.* (*Plate XV, Fig.* 1, *p.* 155, *and Plate XVI, Fig.* 7, *p.* 159.)

Orange sand or stratified drift ....20 feet or more.

1. Dark brown or bluish black, laminated clays, breaking up into small fragments, 6 to 8 feet, at the upper end of the bluff, but rising to 10 feet or more farther down. These clays are identical with those at the base of the White Bluff section ....8 to 10 feet or more.
2. Dark bluish, sandy clay, turning red on exposed and weathered surfaces and capped with a hard ledge which may be easily traced down the river nearly to Davis's Bluff[1] ....3 feet.
3. Bluish, laminated clay or sandy clay, very much like No. 2 in color and texture, but containing no fossils, or very few, and not appearing red at the surface, of variable thickness ....5 to 8 feet.
4. Bluish or greenish, sandy clay, somewhat indurated, of decidedly reddish color on the surface, highly fossiliferous, characterized by *Turritella lineata* Lea and *Dentalium microstriatum* Heilpr., but containing also *Ancillaria staminea* Con., a small Natica *Pyrula multangulata* Heilpr., *Corbula oniscus*, *Infundibulum trochiformis* Lea, a *Phorus*, and a small oyster. The lower part of this bed passes gradually into the greensand marl No. 5 and is the best collecting ground, as the material is less indurated and the shells are more easily removed.....3 to 4 feet.
5. Greensand marl to the water's edge ....10 to 12 feet.

The upper part of this marl is quite soft and friable, but just above the water's edge it becomes indurated and shows a disposition to form rounded, bowlder-like masses, quite hard and firm and resembling a limestone. That this indurated part is of the same nature as the softer greensand above and below it, is seen from the circumstance that the indurated bowlders are sometimes near the top, sometimes near the bottom of the greensand stratum. The accompanying view (Plate VI) shows well the large, bowlder-like masses of the indurated greensand, No. 5. Passing through the central part of this marl bed is a layer of *Ostrea compressirostra* Say, with very thick and ponderous shells.

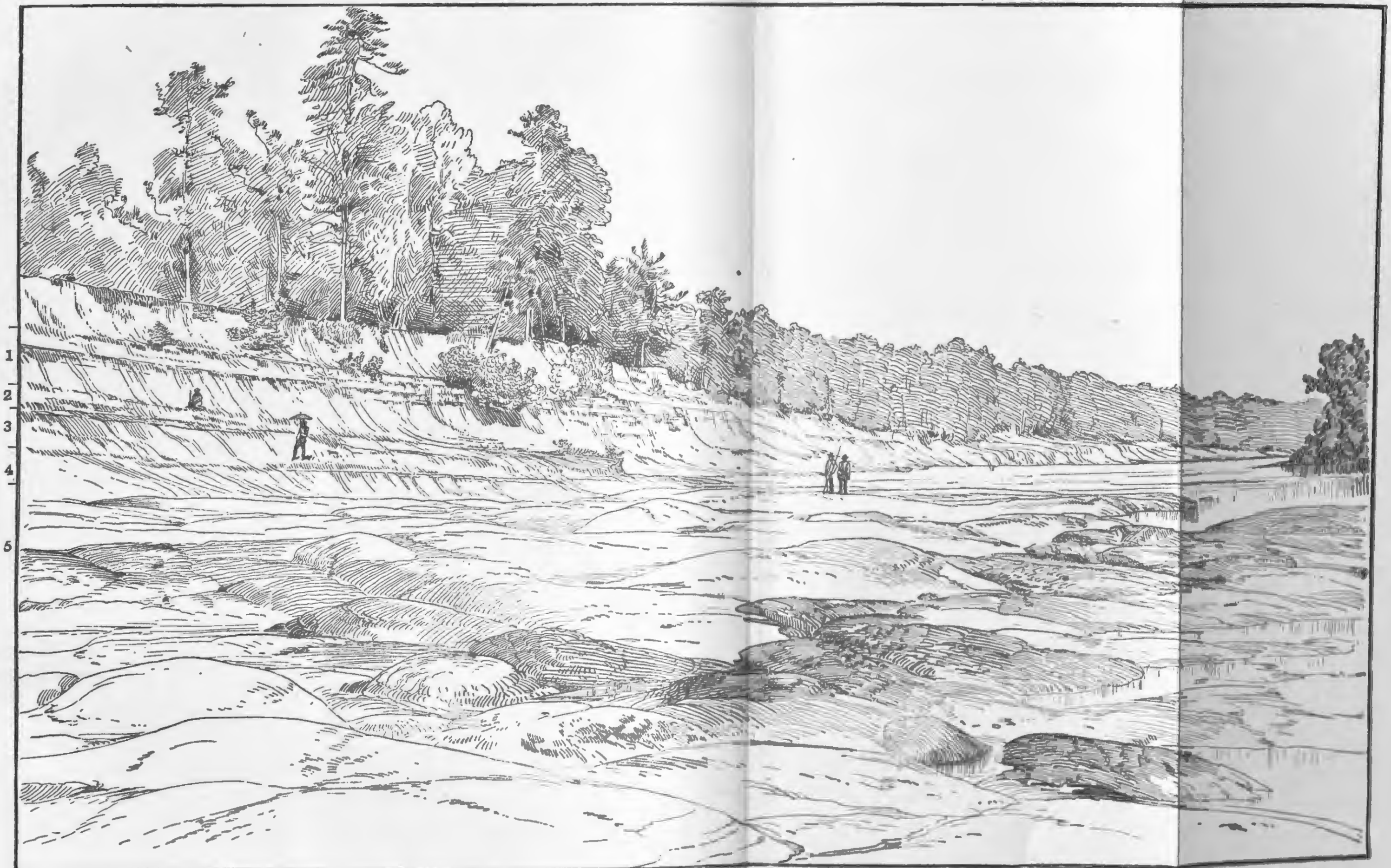
(*b*) About two miles from Wood's Bluff, on the banks of Bashi Creek, there is the following exposure (Plate XVI, Fig. 7, p. 159):

Section near Wood's Bluff.

1. Yellowish gray limestone or indurated marl, like that seen at the base of the Wood's Bluff section ....10 feet.
2. Greenish blue, fossiliferous sands[2] ....8 feet.
3. Seam of lignitic clay, laminated and jointed ....6 inches.
4. Brown, laminated, joint clay, passing below into a greenish, non-fossiliferous sand ....4 feet.

[1] This bed is highly fossiliferous, containing *Lævibuccinum striatum* Heilpr. (which appears to be confined to this particular horizon), *Athleta Tuomeyi* Con., *Fusus pagodiformis* Heilpr., *Venericardia planicosta* Lam., *Actæon pomilius*, Con., a small Natica, *Pleurotoma acuminata* Sow., sharks' teeth, *Ancillaria staminea* Con., a small Cytherea, &c.

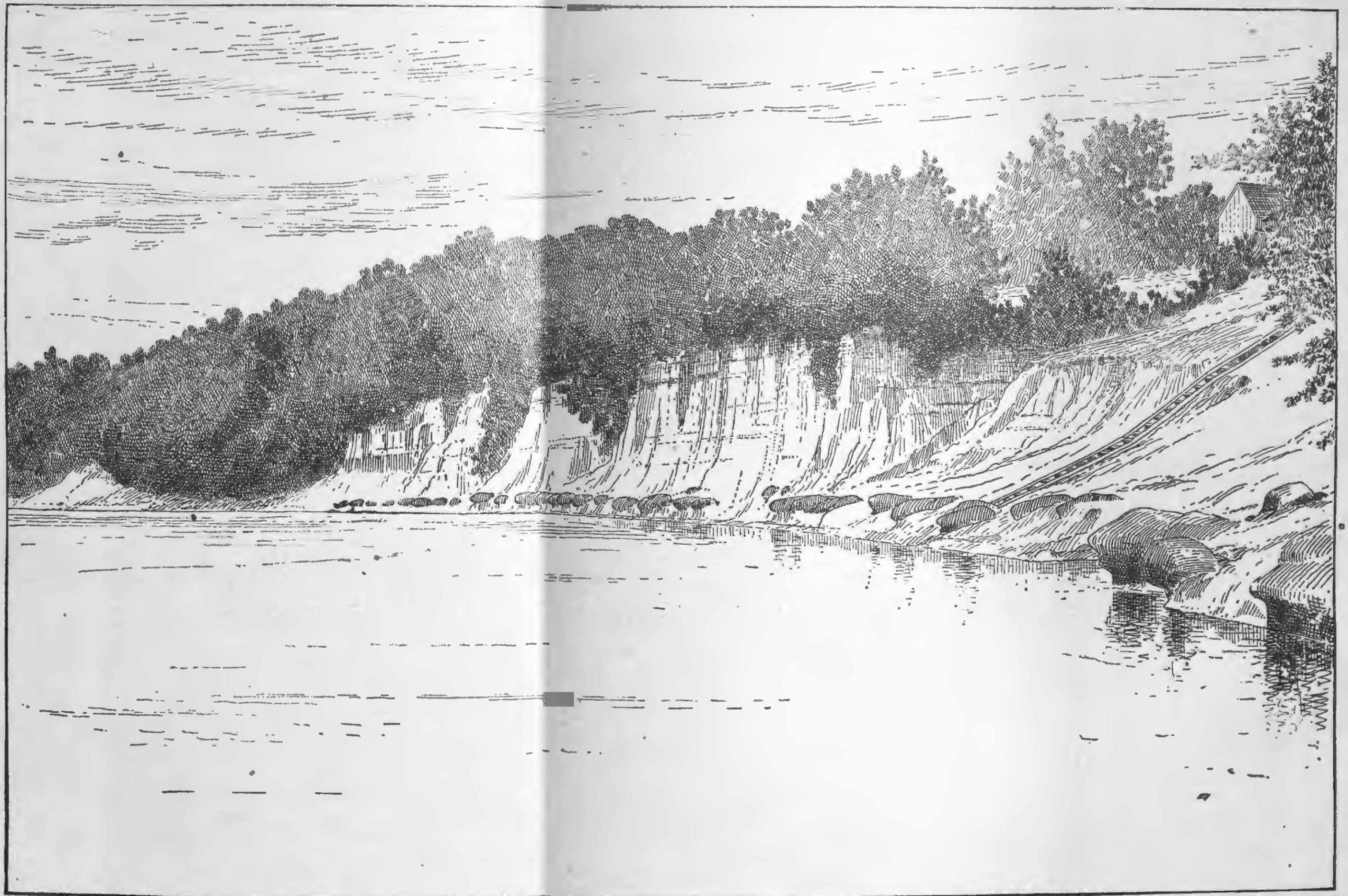
[2] These sands are frequently washed out from beneath the limestone or indurated marl, forming caves which are to be seen wherever the Wood's Bluff marl occurs.



1. Dark gray clays. 2. Bluish, sandy clay, fossiliferous. 3. Bluish, sandy clay, non-fossiliferous. 4. Greenish, sandy clay, highly fossiliferous. 5. Greensand marl.

(The figures refer to sections on p. 44, and also to the section given in Fig. 7 of Plate XVI.)

WOOD'S BLUFF, LOOKING DOWN THE TOMBIGBEE RIVER



YELLOW BLUFF LANDING, ALABAMA RIVER.

5. Laminated, greenish gray clay, alternating with thin seams of dark purplish, lignitic clays, giving the exposure a beautiful and regularly striped appearance[1] .... 5 feet.
6. Thin layer of lignite .... about 12 inches.
7. Gray clay to the water's edge.

(*c*) The strata which intervene between the Wood's Bluff and the Bell's Landing series of marls, together with 130 feet of the beds overlying the former, are to be seen in a continuous section of 250 feet at Yellow Bluff and in the hill which lies just back of the bluff (Plate VII). Here all the strata between the two marl beds mentioned are exposed in actual and unmistakable contact at the river bluff, where there is an uninterrupted section of 120 feet. This is one of the most important sections we have, and it was obtained in the summer of 1885.

Section at Yellow Bluff, Alabama River. (*Plate XVI, Fig.* 1, *p.* 159.)

1. Laminated, gray, sandy clays of light color, variously interstratified with sands; in places there is a white or very light colored clay, and in other places cross-bedded sands, interlaminated with thin sheets of white clay; reddish sand abundant near the top of the section, which is one mile back from the river. Thickness by barometer .... 130 feet.

   These beds are the same as those shown on the Tombigbee River below Wood's Bluff, at Davis's Bluff, and at White Bluff, and belong to the Hatchetigbee series; but, lying high up on the hills and exposed to sun and weather, they are uniformly much lighter in color than on the Tombigbee River, where they are near the water level. Below this we have a gentle slope, along which about fifty feet of beds are exposed (Nos. 2 to 4), and below that the perpendicular bluff of the river, some seventy feet (Nos. 5 to 10).
2. Greensand marl, with Wood's Bluff fossils (*summit of the Wood's Bluff series*), with indurated, rounded masses above, and loose marl below .... about 6 feet.
3. Blue clay .... 1 foot.
4. Gray, sandy clays with a slight tinge of purple, holding four or five thin seams of lignite, each one foot or less in thickness. The actual positions of these lignite beds are slightly obscured by landslides .... 40 to 50 feet.
5. Reddish, cross bedded sands .... 20 feet.
6. Lignitic clay and lignite (*base of Wood's Bluff series*) .... 2 feet.
7. Reddish sands slightly laminated .... 15 feet.
8. Laminated, sandy clays in perpendicular cliff .... 20 to 25 feet.
9. Greensand marl in two parts separated by one foot of sandy clay without fossils. The upper part, one foot thick, holds chiefly *Ostrea compressirostra* and *Venericardia planicosta*, while the lower part, six feet thick, contains all the characteristic fossils of the Bell's Landing series, *Voluta Newcombiana*, large *Turritella Mortoni*, *Rostellaria trinodifera*, &c. This upper part shows strong tendency to harden into round, bowlder-like masses; in all .... about 8 feet.

   This bed, No. 9, is very clearly marked in the accompanying view (Plate VII) by the line of bowlders near the water's edge. The lignite, No. 6, occurs near the top of the cliff, but does not show out in the picture.
10. Greenish, ferruginous sands interlaminated with thin sheets of clay, passing into a dark blue, sandy clay at the water level .... 7 feet.

In this section the beds numbered 5 to 10, inclusive, are seen in the actual bluff of the river about half a mile or less below the steamboat

[1] The dark clays in this stratum appear to resist denudation better than the greenish clay, so that they project slightly from the face of the bluff.

landing. The beds numbered 2 to 4, inclusive, together with about forty feet of the lower strata of No. 1, are seen on the top of the bluff, along the road leading up the hill, and they directly overlie the beds exposed in the river bluff. Nos. 2 to 6, inclusive, represent the Wood's Bluff series.

From the sections represented on Plates XV and XVI it will be seen that the Wood's Bluff marl lies embedded in a great thickness of clays and clayey sands, a circumstance which has an important bearing upon its economic value. The disintegration of the clays produces heavy clay soils, which are thoroughly marled by the Wood's Bluff beds, and they form in consequence some of the most productive and lasting soils of the Tertiary group. We have as instances the heavy, calcareous, clay soils which occupy a broad belt north of Butler, in Choctaw County; the productive soils of parts of the Tallahatta and Bashi Creeks region; the clay hill soils of the eastern part of Clarke and the western part of Wilcox Counties, between Choctaw Corner and Lower Peach Tree; the celebrated Flat Creek lands of Monroe County, &c. Some descriptions of these soils, with analyses, were presented in the Report of the Geological Survey of Alabama for 1881–'82.

(3) THE BELL'S LANDING SERIES. (PLATE XVI, FIGS. 1 TO 6, P. 159.)

This series includes two important fossiliferous beds, separated by about twenty-five feet of gray, sandy clays. Between the lignite, which forms the base of the preceding division, and the upper marl of this series there are some forty feet of reddish sands and laminated, gray, sandy clays, and below the lower marl about sixty feet of sandy clays of the prevailing gray color, rather massive in the lower part. About fifty feet below the lower of the two marl beds, and ten feet above the base of this series, there is a third small greensand bed one foot or less in thickness containing fossils. The entire series comprises about one hundred and forty feet of strata, which, as a whole, are gray, sandy clays, becoming more and more massive toward the base, while they are more thinly laminated and more mixed with sands near the summit of the section. The strata which lie between the Wood's Bluff marl and the uppermost of this series are about sixty feet of sandy clays, containing several thin seams of lignite, all of which are exhibited in direct superposition at Yellow Bluff, and have been placed, as above shown, with the Wood's Bluff series. The upper marl bed, which is the Bell's Landing marl bed proper, is some ten feet thick, contains greensand, and indurates into bowlders, fine examples of which are to be seen at the base of the bluff at Bell's Landing. This marl is characterized above all others in the Tertiary of Alabama by containing gigantic specimens of shells which at other localities are of moderate size. The lower bed, known as the Gregg's Landing marl from its occurrence at the landing of that name, is four or five feet in thickness and is of clayey material. It has a peculiar group of fossils.

The fossil bearing beds of this series are best exposed along the banks of the Alabama River at Bell's Landing, Gregg's Landing, Peebles's Landing, Lower Peach Tree, and Yellow Bluff; and on the Tombigbee at Tuscahoma, Turner's Ferry, near the mouth of Shuquabowa Creek, and at Barney's Upper Landing. The exposures on the Alabama are much more satisfactory.

Unlike the Wood's Bluff marl, the marls of this series make comparatively little show inland from the rivers and exercise little, if any, influence upon either the soils or the topography of the country in which they come to the surface. I am not certain that either the Bell's Landing marl or the Gregg's Landing marl has been identified at any distance from the rivers, while the Wood's Bluff marl can be followed with ease from the Mississippi line as far eastward as we have been.

The following sections illustrate the occurrences of the Bell's Landing beds along the two rivers:

(*a*) *Section at Bell's Landing, Alabama River.* (*Plate XVI, Fig.* 2, *p.* 159.)

1. Yellowish red, cross bedded sands..15 feet.
2. Lignite ....about 2 feet.
3. Laminated, sandy clays, with a few large, bowlder-like concretions......10 feet.
4. Yellow, stratified sands alternating with gray, sandy clays..............15 feet.
5. Gray, sandy clays...15 feet.
6. Greensand marl forming large concretionary bowlders and holding gigantic specimens of *Rostellaria trinodifera, Turbinella pyruloides* Con., *Fusus pagodiformis* Heilpr., *Voluta Newcombiana* Whitfield, &c. The bowlders cover all the lower part of the slope below the landing. The marl beds .... about 6 to 10 feet.
7. Dark gray, laminated, sandy clays, black when wet, but light gray when dry..25 feet.
8. Bluish green, sandy clay marl ....1 to 2 feet.
9. Dark gray, sandy clay to water level ....4 feet.

Above Bell's Landing the strata of this series are exposed along the river as far as Yellow Bluff, and the most important localities are given below.

(*b*) *Section at Gregg's Landing, Alabama River.* (*Plate XVI, Fig.* 4, *p.* 159.)

1. Greensand marl with concretionary bowlders, the same as No. 6 at Bell's Landing..5 feet.
2. Gray, sandy clays ....20 to 25 feet.
3. Dark gray or bluish, sandy clay or clayey sand containing well preserved fossils, many of which are peculiar, and some identical with those at Wood's Bluff, such as *Pyrula multangulata* Heilpr. and *Fusus subscalarinus* Heilpr. This bed has an indurated ledge of variable thickness at the base and is in all...about 4 to 5 feet.
4. Laminated, sandy clays to the water level..............................about 10 feet.

This bluff extends at least one mile down the river from the landing, and along this whole distance there have been landslides, and the two marl beds have in consequence been thoroughly mixed up. In some places the upper marl has slid down and completely covered the lower; in other places the lower marl is in its proper position, but the upper has slipped down *below* it; sometimes the two are in direct contact, the upper above; but in all cases a careful inspection of the original bluff a short distance back from this river slope will reveal the true relative position of the two beds. I am particular in calling attention to these circumstances because at many points these broken off parts of the bluff appear to be in place, and where the two beds, apparently in place, are thus brought into contact or their relative positions are reversed the commingling of the two sets of fossils would lead the incautious observer far astray.

The next exposure is about a mile below Lower Peach Tree, at Peebles's Landing.

(c) *Section at Peebles's Landing, Alabama River.* (*Plate XVI, Fig.* 3, *p.* 159.)

1. Yellow sands ....1 foot.
2. Lignite and lignitic clay ....about 2 feet.
3. Reddish, laminated sands ....10 feet.
4. Dark gray clays and sands interstratified ....30 feet.
5. Greensand marl, No. 6 of Bell's Landing section..8 feet.
6. Dark gray clays and sands variously interstratified ....25 feet.
7. Dark bluish gray, clay marl, Gregg's Landing ....2 feet.
8. Dark gray sandy clays extending to the foot of hill, 20 feet above the river level..about 14 feet.

The next locality is Lower Peach Tree, where we have a repetition of the above section, together with beds extending some 45 to 50 feet lower.

(*d*) *Section at Lower Peach Tree, Alabama River.* (*Plate XVI, Fig.* 5, *p.* 159.)

1. Sandy, laminated clays at the top of the bluff..about 10 feet.
2. Greensand marl containing the characteristic fossils of the upper bed at Bell's Landing..8 to 10 feet.
3. Sandy, laminated clays, of gray color, but with some reddish layers..20 to 25 feet.
4. Bluish, sandy, clay marl containing a number of peculiar fossils. To this bed we have given the name of *Gregg's Landing Marl*, as it is seen at Gregg's Landing better than elsewhere..5 feet.
5. Sandy clays of prevailing gray color, varying in degree of sandiness and coarseness of lamination, without fossils so far as we could discover..50 feet.
6. Coarse grained greensand marl, indurating into bowlders in places, containing some fossils, which are also in the bed No. 4, above..1 foot.
7. Gray, sandy clays to water level..10 feet.

The last exposure of the beds of this series up the Alabama River is seen at Yellow Bluff, the section of which has already been given (Plate XVI, Fig. 1).

The exposures at Lower Peach Tree and at Yellow Bluff, in part overlapping, give us a continuous section of some 250 feet, and the two, taken with the exposures at Wood's Bluff, Davis's Bluff, White Bluff, and Hatchetigbee, all of which overlap in some parts, afford a series which is without a break from the base of the Buhrstone down 390 to 400 feet. It would be impossible to find anything more satisfactory for making out the stratigraphy of this part of the Tertiary group.

On comparison of all these sections it will be seen that the Bell's Landing marl, at Bell's Landing, is about 30 feet above the river level; at Gregg's Landing, about 40 feet; at Peebles's Landing, about 60 feet;

at Lower Peach Tree, 85 feet or more; while at Yellow Bluff it is only about 7 feet above the river level. The beds rise with tolerably uniform inclination (40 feet to the mile) up to the Lower Peach Tree, and then sink rapidly, Lower Peach Tree being about on the summit of the anticlinal or roll. As a consequence of this undulation the beds involved are spread in a north and south direction over a much greater extent of surface than is usually the case where the average dip is uniformly southward some 30 or 40 feet to the mile. This roll in the strata may be traced from Choctaw County to Monroe County, but seems to be most pronounced in the lower part of Marengo County and the upper part of Clarke County. In the southern part of Wilcox County and the northern part of Monroe County the undulation involves in general a lower series of rocks, to be mentioned presently.

On the Tombigbee River the strata between the Wood's Bluff marl and the Bell's Landing marl at Tuscahoma are not well exposed, and it would have been impossible to get any clear understanding of the stratigraphy from the bluffs of that river alone. It is fortunate that the section, here so faulty, is so complete and satisfactory on the Alabama River.

The few localities where Tertiary strata make the banks of the river, from Wood's Bluff up to Tuscahoma, are given below.

Across a narrow neck of land from Wood's Bluff at Cade's Bend, the Wood's Bluff marl is again seen in the river bluff.

At the mouth of Bashi Creek, as above shown (see Plate XVI, Fig. 7, p. 159), the lower strata of the marl, as well as two of the underlying lignites, are exposed.

Two others of these lignites are seen a little higher up the river, at Pickens's Landing, where we have the following section:

(e) Section at Pickens's Landing, Tombigbee River.

1. Gray, laminated, sandy clays	10 feet.
2. Lignite	12 to 18 inches.
3. Bluish, clayey sands with yellowish division planes	6 to 8 feet.
4. Lignite	2 feet.
5. Gray, sandy clays to water level	1 to 2 feet.

The beds are undulating and in some places show a dip towards the northwest, but the general dip of the surrounding strata is southwest.

Above Pickens's Landing gray, sandy clays are shown in the river banks at Magnolia Landing and one or two other points; but these clays contain no fossils, so far as our observations went. The Pickens's Landing lignites are found in the hills about the headwaters of Horse Creek and elsewhere in the lower part of Marengo County.

At Tuscahoma we have the first considerable bluff above Wood's Bluff. In the section below given we include not only the strata actually appearing in the bluff at the landing, but also those which make the bank for half a mile or more down the river. This section, as will be seen, is about the equivalent of that at Yellow Bluff on the Alabama.

(f) Section at Tuscahoma, Tombigbee River. (*Plate XVI, Fig.* 6, *p.* 159.)

1. Indurated sands, with a line of bowlders at the base. This stratum is eight to ten feet thick at the warehouse, but down the river it thickens to twenty feet or more, and a second line of ferruginous, indurated bowlders appears about ten feet above the first. The strata above this upper string of bowlders are more distinctly laminated and interbedded with thin sheets of clay. This is most clearly shown about six to eight feet above the upper line of bowlders. Taken all together there are .... about 30 feet.
2. Light bluish gray, sandy clays, which are somewhat striped with harder projecting seams .... 35 to 40 feet.
3. Sandy marl, containing the Bell's Landing fossils, but in badly preserved condition .... 2 feet.
4. Dark blue, massive clay .... 3 to 4 feet.
5. Thin streak of greensand, with *Venericardia planicosta* and other Bell's Landing fossils to water level .... 6 inches or more.

About half a mile below the landing there is a low bluff capped by the upper string of bowlders above mentioned, which form a little terrace forty or fifty feet wide, the farther limit of which is made by another low bluff of second bottom deposits.

The lignite which occurs about thirty-five to forty feet above the marl bed at Yellow Bluff and at Bell's Landing was not observed at Tuscahoma, those parts of the bluff where it would be looked for being badly weathered.

The massive clay, No. 4, which separates the two parts of the marl bed, is everywhere perforated by pholas, and in most of the perforations their shells are still to be found. Mr. T. H. Aldrich, who made this observation, also saw these shells in the clay which occurs below the lower marl bed at Bell's Landing.

The Tuscahoma (Bell's Landing) marl, with its accompanying beds, may be followed up the river without essential interruption to Barney's Upper Landing, as shown in the following sections (Plate XVI, Fig. 6, p. 159):

(g) Section at Turner's Ferry, Tombigbee River.

1. Indurated sands, No. 2 of the Tuscahoma section .... 5 feet.
2. Marl with badly preserved shells .... 3 to 4 feet.
3. Bluish clay, becoming sandy below .... 3 to 4 feet or more.

From Turner's Ferry these beds rise, going up stream, and at the mouth of Shuquabowa Creek they give the following section:

(h) Section at mouth of Shuquabowa Creek, Tombigbee River.

1. Greensand marls .... 3 to 4 feet.
2. Dark bluish black, massive clay .... 2 feet.
3. Hard sands, passing into sandy clay below .... 5 feet.
4. Light colored, nearly white, cross bedded sands, about 3 feet, with 3 to 4 feet below it of sands with clay partings, in all .... 6 to 8 feet.

Above this place the strata sink towards the north, and at Barney's Upper Landing only three feet of the beds immediately below the marl are above the water, as seen below.

(i) Section at Barney's Upper Landing, Tombigbee River.

1. Laminated, sandy clays, striped with somewhat harder and more clayey seams, in all .... 15 to 20 feet.
2. Sandy, fossiliferous bed, with greensand in the lower parts, more clayey above. The fossils in this bed are badly preserved, as was the case also at Tuscahoma, Turner's Ferry, &c., but are the characteristic Bell's Landing forms ...... 5 feet.
3. Dark bluish to gray clays to water level .... 3 feet.

From Barney's Upper Landing to the mouth of Horse Creek no Tertiary strata appear on the river banks, but just above that point the river bank is formed by dark gray, clayey sands or sandy clays, which continue up to Williams's Gin, where they overlie the first of the beds containing *Gryphæa thirsæ* Gabb, and in consequence may be better classed with the next section.

(4) THE NANAFALIA SERIES, INCLUDING THE COAL BLUFF LIGNITE.

The series of strata to which the Nanafalia marl has given the name, broadly considered, is susceptible of threefold division upon the basis of lithological and paleontological characters, viz:

First. Forty feet or more of indurated, gray clays and sandy clays, in part glauconitic and rather closely resembling some of the materials of the Buhrstone. Near the base of this first division there are hard, sandy clays filled with shell casts, chief among which are Turritellas and Cythereas.

Second. Seventy-five to eighty feet of yellow and reddish and whitish sands, alternating with greensand beds, highly fossiliferous. The characteristic shell in both the sands and the greensands is *Gryphæa thirsæ* Gabb. In the upper fifty or sixty feet of this division this shell is found either in thin greensand beds or sparingly distributed through the other sands. In the lower twenty feet there are thick greensand beds literally packed with these shells. The greater part of the exposure at Nanafalia Landing consists of greensand beds filled with *Gryphæa thirsæ* and other forms, the first named making perhaps 90 per cent. of the whole.

Third. Below the *Gryphæa thirsæ* beds follow some eighty feet or more of sandy clays and sands, variously interstratified, cross bedded sands passing near the base of the division into greensands which overlie a bed of lignite varying from four to seven feet in thickness.

It is easily possible to obtain overlapping sections which embrace the whole series of about two hundred feet; thus in the bluff at Gullette's Landing, on the Alabama River, nearly the whole of the two upper divisions are represented, while on Pursley Creek, a few miles eastward, the lower part of the second division and the whole of the third are shown in direct contact, the whole series being thus represented at two localities.

Between the heavy bedded, sandy clays exposed at the base of the Lower Peach Tree Bluff and those which are seen at the top of the bluff at Gullette's Landing there is a series of glauconitic clays and clayey sands which have a tendency to harden into pretty firm rocks, having a striking resemblance to some of the materials of the Buhrstone formation, but which are readily distinguished from the latter by one familiar with both of them. These rocks are shown in the hills which rise immediately back of Gullette's Landing and Black's Bluff (Alabama River) to the height of two hundred and fifty to three hundred feet above the river level, and they are seen again in the Grampian Hills of Wilcox County. We have not as yet been able to connect the beds at Lower Peach Tree with those at Gullette's Landing by an overlapping section which includes a part of each, and there is therefore a little uncertainty as to the precise thickness of these beds, though none as to their quality. There is very little doubt that the lower beds of the Lower Peach Tree Bluff are exposed in the hills back of Gullette's Landing and Black's Bluff, but, as already said, this identity is not absolutely made out. The uncertainty, however, cannot concern more than twenty or thirty feet of strata, if so much. Still, it is much to be regretted that even this slight hiatus exists, since from the top of the White Limestone down to this point every foot of the strata has been exhibited in overlapping sections, so that there is not the slightest room for doubt as to their relative position or thickness, nor is there the slightest room for doubt as to relative position here, but only as to exact thickness.

Before giving the section at Gullette's Bluff Landing, some notes concerning the indurated clays and sands that immediately overlie the rocks at the last named locality, and which are seen in the Grampian Hills, will serve to bring out their peculiarities, especially the points of resemblance between them and certain of the materials of the Buhrstone.

About three miles south of Camden, in the Grampian Hills, we find the following:

(*a*) *Section in Grampian Hills, No.* 1.

1. Light-colored, argillaceous, sand rock, containing casts of *Cytherea, Turritella, Voluta,* &c. This passes below into a clayey stratum, which in turn is underlaid by a hard, sandy rock containing many shell casts, particularly of *Turritella Mortoni* Con. .... 5 feet.
2. Gray, clayey beds, breaking into small angular bits .... 5 feet.
3. Ledge of glauconitic, clay rock, sandier below and breaking by joints into large cuboidal blocks of tolerably hard sandstone, containing also a great number of shell casts .... 2 feet.
4. Gray clays resembling those of the Buhrstone, but softer and crumbling more easily .... 15 feet.
5. Glauconitic sands, indurated, filled with casts of *Gryphœa thirsœ* (*first of the Gryphœa thirsœ beds*) .... 2 feet.
6. Greensand beds, with perfect shells of *Gryphœa thirsœ* .... 7 to 8 feet.
7. Dark gray clays .... 2 to 3 feet.
8. Yellowish, calcareous sands, with *Gryphœa thirsœ, Flabellum, Venericardia planicosta,* &c .... 4 to 5 feet.
9. Bed of *Gryphœa* shells .... 1 foot.
10. Yellowish, calcareous sands, with concretionary bowlders, containing *Gryphœa thirsœ* and casts of other shells .... 6 to 8 feet.

Half a mile farther south, other beds overlying No. 1 of the above are seen, as shown below.

(*b*) *Section in Grampian Hills, No.* 2.

1. Whitish, sandy rock, indurated, containing shell casts.................... 1 foot.
2. Whitish clay rock.. 1 foot.
3. Hard ledge of sandy rock, with casts of Turritella, Cytherea, &c............ 2 feet.
4. Gray clays, indurated, and greatly resembling some of the Buhrstone clays, 10 to 15 feet.
5. Ledge of indurated glauconitic clay, the lower 12 or 18 inches of which are sandier and filled with shell casts, mostly of *Turritella Mortoni* Con., same as No. 1 of preceding section.. 3 to 4 feet
6. Gray, crumbling clays, with indurated ledge of hard, glauconitic clay in center.. 6 feet.
7. Hard ledge of glauconitic clay or sandstone breaking by joints into large cuboidal blocks.. 4 feet or more.
8. Laminated gray clays resembling those of the Buhrstone, breaking up into small bits.. 12 feet,
9. Glauconitic sands, indurated, containing casts of *Gryphœa thirsœ* in the upper part and perfect shells of the same in the lower part.................... 1 foot.
10. Greensand, with occasional shells of *Gryphœa thirsœ*.................... 5 feet.
11. Yellowish sand filled with shells of *Gryphœa thirsœ*.................... 1 foot.
12. Laminated, yellowish sands, with a few shells of *Gryphœa thirsœ*.......... 4 feet.

The relations between these two sections and the others which exhibit the same strata are more clearly seen in Plate XVII, Fig. 2, p. 163, which is a representation of the two preceding profiles combined.

The Grampian Hills extend westward to the river at the Lookout, which is a cliff reaching fully 275 feet above the river level. This cliff is half a mile or more above Gullette's Landing, and in its lower half the beds which make the bluff at Gullette's Landing are exposed by a landslide in a perpendicular section of nearly 150 feet. Above this a very steep, almost precipitous hill rises 125 feet higher. In this upper part of the hill the rocks are not clearly exposed, but they consist of gray, laminated clays, interstratified with heavy bedded, massive clays, such as are seen in the lower part of the Lower Peach Tree Bluff, with which they are probably, in part at least, identical. No fossils were discovered in these clays, which include in places indurated bowlders of calcareous sand. In the lower part of the hill, hard, glauconitic, sandy clays with shell casts are abundant and correspond in position, as well as in other respects, to those represented in the upper members of the two preceding sections.

At Gullette's Landing a cut has been made for the cotton slide and tramway down to the river level through the strata of the bluff, which are thus very clearly exposed almost as if in a vertical wall.

(*c*) *Section at Gullette's Landing, Alabama River.* (*Plate XVII, Fig.* 1, *p.* 163.)

1. Drift and loam.. 10 feet.
2. Indurated, glauconitic clay, forming ledge................................ 3 feet.
3. Gray, sandy clays, thinly laminated and heavy bedded alternating........ 12 feet.
4. Glauconitic sand, very green in places.................................... 2 feet.
5. Gray and sandy clays, like No. 3.. 20 feet.
6. Glauconitic. sandy ledge, fossiliferous (*the first of the Gryphœa thirsœ beds*).. 3 feet.
7 Compact; yellowish sands holding *Gryphœa thirsœ*, and forming a vertical cliff, capped with an indurated ledge a foot in thickness.................... 13 feet.

8. Indurated sandy ledge .... 2 feet.
9. White, cross bedded sands .... 12 feet.
10. Bluish sands, forming a vertical cliff. These contain numbers of *Gryphæa thirsæ* and have an indurated ledge in the midst of the bed, and one at the bottom .... 20 feet.
11. Bluish, clayey sands containing a few *Gryphæa* .... 10 feet.
12. Sands containing *Gryphæa thirsæ*, traversed by several indurated projecting ledges; materials are of darker color and more clayey below to water level .. 20 feet.

At Black's Bluff, Alabama River, about a mile or less below Gullette's Landing, there is a similar section, which, however, is not so clearly exposed. Above the warehouse at this landing, the strata are the same as those at the top of the bluff at Gullette's Landing, but there have been many landslides, by which the relative thickness and positions of the beds here are obscured. Between these two places the river flows approximately along the strike of the strata, which, however, do not lie horizontal, but show one or two undulations with twenty or thirty feet wave height.

The actual contact of the strata of the Bell's Landing and the Nanafalia series fails to appear in the bluffs of the Tombigbee River also, as may be seen in what follows. From Barney's Upper Landing, described in the preceding section, up to the mouth of Horse Creek, no Tertiary beds appear in the river banks. Just above the mouth of this creek grayish, sandy clays occur similar to those which make up the lower 50 feet of the Lower Peach Tree Bluff, and these clays may be traced foot by foot up the river or northward to Williams's Gin, half a mile or so below Gay's Landing, where they are seen overlying the first of the beds holding *Gryphæa thirsæ*. A section of these strata is given below. (See Plate XVII, Fig. 4, p. 163.)

The grayish, sandy clays which overlie these Gryphæa beds are undoubtedly the same as those at Lower Peach Tree, but here also the exact thickness cannot be measured because of their failure to appear in the banks of the river. Still, unless in this short distance of less than a mile there is a fault or a very violent, decided change in the dip of the strata, the thickness of the beds not exposed on the river cannot be much more than fifty feet, if so much.

The strata exposed at Williams's Gin and along the river for half a mile up to Gay's Landing are as follows (see Plate XVII, Fig. 4, p. 163):

(*d*) *Section from Williams's Gin to Gay's Landing, Tombigbee River.*

1. Gray, sandy clays, thin bedded, reddish on joint planes, passing below into an indurated ledge of lighter color .... 8 feet.
   About 20 feet more of similar sandy clays appear in the banks of the river, between the mouth of Horse Creek and Williams's Gin, as above mentioned, making the whole thickness actually exposed on this river, between the top of the Gryphæa beds and the bottom of the Bell's Landing marl at Barney's Upper Landing, about thirty feet.[1]

[1] In bed No. 1 above I found a specimen of *Voluta Newcombiana* Whitfield, which heretofore was seen only in the Bell's Landing marl bed and which seemed to be characteristic of it.— E. A. S.

2. Indurated, glauconitic bed, with *Gryphæa thirsæ* ....2 feet.
3. Dark blue, nearly black, jointed clays, with thin, hard ledges.................6 feet.
4. Indurated, sandy, fossiliferous bed, with a few *Gryphæa* and other forms .2 to 3 feet.
5. Bluish black clays, with ferruginous concretions at base ....3 feet.
6. Greensand bed, with *Gryphæa thirsæ* to water ....3 feet.

Above Gay's Landing there is a long stretch of several miles in which no Tertiary rocks show on the river banks; but at Lott's Ferry the Gryphæa beds make their appearance again and may be followed thence without material interruption to Eureka Landing and to Nanafalia, a distance in all of perhaps two miles.

These exposures exhibit the following details:

(*e*) *Section at Lott's Ferry, Tombigbee River.* (*Plate XVII, Fig.* 4, *p.* 163.)

1. Dark gray, nearly black, sandy clay, weathering light gray, containing a few fossils...5 feet.
2. Indurated, sandy marl, containing *Gryphæa* in places. This bed varies, being in part a cross bedded sand devoid of fossils ....3 feet.
3. Dark, sandy clays, with a few very badly preserved fossils ....2 to 3 feet.
4. Glauconitic, sandy beds, with *Gryphæa thirsæ*. This bed is only a few feet thick at Lott's Ferry, but just above shows ....20 to 30 feet.

All the Tertiary beds about Lott's Ferry exhibit decided undulations. Bed No. 4 of the preceding section sinks entirely below the water and rises again 20 feet or more above it within the distance of a few hundred yards. All these beds probably overlie the section at Nanafalia below given.

At Eureka Landing there are some 20 to 25 feet of a glauconitic, sandy marl (probably the same as part of the upper bed at Nanafalia) filled with *Gryphæa thirsæ*, associated with very few other forms. This makes a tolerably firm rock, which appears in vertical bluffs, usually capped by hard ledges of the same material, and these ledges are mostly strongly phosphatic.[1]

At Nanafalia we have the lowermost of the Gryphæa beds, as shown in the following section:

(*f*) *Section at Nanafalia Landing, Tombigbee River.* (*Plate XVII, Fig.* 4, *p.* 163.)

1. Greensand marl, highly fossiliferous, containing chiefly *Gryphæa thirsæ* Gabb, but holding also *Turritella Mortoni* Con., *Flabellum*, and a few other fossils. This marl makes a tolerably firm rock, with a line of indurated, projecting bowlder-like masses 12 to 18 inches thick of nearly similar material along the whole length of the bluff and near the middle of the bed................about 20 feet.
2. Dark blue, almost black, laminated clay, devoid of fossils, but passing below gradually into a bluish marl ....3 to 4 feet.
3. Bluish greensand marl, with a few shells in the upper 3 or 4 feet, but more highly fossiliferous below. This bed contains a great variety of beautifully preserved and easily detached fossils. The fossils can be collected only during very low stages of the water ....8 to 10 feet.

[1] Specimens of the indurated ledges of the *Gryphæa thirsæ* beds from Nanafalia and Eureka Landing, collected in 1884 by Mr. Langdon, prove to be very decidedly phosphatic; one of the specimens analyzed quantitatively contained 6.7 per cent. of phosphoric acid.

The view (Plate VIII) shows clearly the greensand No. 1, with its line of indurated bowlders along the center. The large rocks in foreground are part of this indurated marl.

The Nanafalia marl, like that of Wood's Bluff, is one of our most important geological landmarks, both because of its tendency to form by induration tolerably firm and weather resisting rocks and because of the influence which it exerts upon the soils. If there were any doubt as to the agricultural value of either the Wood's Bluff or the Nanafalia marls, it would be dispelled by an inspection of the fertile, naturally marled soils produced where these beds come to the surface across the country.

About 60 feet below the lowermost of the beds containing *Gryphæa thirsæ*, above described, there is an important bed of lignite, which shows a thickness of 4 feet at Coal Bluff, on the Alabama River, and of 7 feet at Landrum's Creek, in Marengo County, near Nanafalia Landing. This lignite appears also at many localities in Marengo and Wilcox Counties, e. g., near Shiloh, Magnolia, Hampden, &c., always in connection with the Gryphæa beds, the latter on the summits of the hills, the former 60 feet below in the branches; and, as the Gryphæa marl usually produces very characteristic limy soils, it is not difficult to trace it, as well as the lignite, across the country.

Between the Gryphæa beds and the lignite, the strata are chiefly sands, mostly glauconitic, alternating with sandy clays of grayish colors. The greensands when weathered appear as yellowish or ferruginous sands, and this is the prevailing color upon the hills, while some shade of green or blue characterizes them near the drainage level, where oxidation is less complete. None of these beds are seen on the immediate banks of the Tombigbee River, and only about 30 feet immediately overlying the lignite occur on the banks of the Alabama; but they may all be seen in direct superposition in the hills which border Pursley Creek on the south, where they are laid bare by the road leading from Black's Bluff to Camden.

This section is complete, as may be seen below.

(*g*) *Section on Pursley Creek, Wilcox County.* (*Plate XVII, Fig.* 3, *p.* 163.)

1. Drift and loam and other beds, much weathered and not further particularized .... 10 to 15 feet.
2. Dark colored, crumbling clays .... 5 feet.
3. Sands containing *Gryphæa thirsæ* and a few other fossils .... 5 feet.
4. Thin bedded sands and sandy clays, partly glauconitic, with a few obscure fossils .... 15 to 20 feet.
5. Yellowish gray, cross bedded sands, with concretionary bowlders of the same material. These sands hold also at intervals lenticular sheets of gray clay. 25 to 30 feet.
6. Interstratified sands and clays, of grayish color with a shade of yellow, rather thin bedded .... 10 to 15 feet.
7. Gray, sandy clays, exposed in the immediate banks of Pursley Creek below the bridge .... 6 to 8 feet.
8. Lignitic clay, thickness not determined.

NANAFALIA LANDING, TOMBIGBEE RIVER.

Along the Alabama River no Tertiary strata are to be seen from near Gullette's Bluff to the mouth of Pursley Creek. Just above the last named point, however, there is a continuous exposure of these strata up to Coal Bluff, as shown in the following:

(*h*) *Section between mouth of Pursley Creek and Coal Bluff.* (*Plate XVII, Fig.* 1, *p.* 163.)

1. Greensand at mouth of Pursley Creek ....5 feet.
2. Sands, with an indurated ledge one foot thick at top ....3 feet.
3. Laminated, clayey sands, with a hard projecting ledge at top and one or two lower ones .... 6 feet.
4. Indurated greensand, forming a ledge ....3 feet.
5. Greensand of softer texture, easily washed out by the waters and forming shallow caves below the preceding ....5 feet.
6. Greensand of firm texture, with a bed of brownish sand one foot thick at the base ....8 feet.
7. Lignite of Coal Bluff ....4 feet.
8. Firm, sandy clays appearing just above the Coal Bluff Landing ....10 feet.

These beds, as exposed on Landrum's Creek (Sec. 23, T. 14, R. 2 E.), are as follows:

(*i*) *Section on Landrum's Creek, Marengo County.* (*Plate XVII, Fig.* 4, *p.* 163.)

1. Bluish green, micaceous sands ....12 to 15 feet.
2. Lignite .... 7 feet.
3. Dark gray, sandy clay ....2 feet.

The lignite here also is 60 feet, by barometric measurement, below the lowermost of the Gryphæa beds, which may be seen on all the hills in the vicinity, where they produce limy soils of great fertility. In most of these limy soils are embedded rounded or water worn fragments of indurated marl.

In many places in Marengo County and elsewhere the greensands overlying the lignite are thoroughly oxidized into a brown iron ore. This may be seen near Magnolia, near Hampden, and near Dumas's Store.

(5) THE NAHEOLA AND MATTHEWS'S LANDING SERIES.

The strata which make up this series are mostly gray sandy clays alternating with cross bedded sands, with a bed at the base of the section containing marine fossils, and consisting of glauconitic sands and dark gray, nearly black, sandy clays. The thickness of these strata varies from west to east, being 150 feet or more on the Tombigbee River, and not more than 125 or 130 at Oak Hill, in Wilcox County.

In 1883 we failed to establish the identity of the Naheola marl on the Tombigbee with that of Matthews's Landing on the Alabama, for the reason that at the former place the upper part of the marl is most conspicuous, and was the only part examined by us, while at Matthews's the bluff is made up of the black or dark gray sandy clays which form the lower part of the marl bed. In the summer of 1886 I made a reexamination of the exposures along the Tombigbee River, and found at

Naheola the black, clayey marl, identical both in material and in fossil contents with that at Matthews's.

On the Tombigbee River there are no Tertiary rocks exposed in the river bluffs between Nanafalia, which lies near the base of the preceding section, and the mouth of Beaver Creek, a distance of about four miles. With an assumed uniform dip of some 30 feet to the mile, this would indicate a thickness of about 120 feet of strata. But from the undulations seen at Lott's Ferry (below Nanafalia) and elsewhere along this river, it is known that the dip is not uniform, and the thickness of the missing beds is probably less than the estimated 120 feet.

From the mouth of Beaver Creek to Naheola there is an almost continuous exposure of Tertiary rocks along the river bank, embracing about 80 feet of strata, making, with the 120 feet estimated above, 200 feet intervening between the base of the Nanafalia marl and the top of the Naheola marl. Of these 200 feet we know from exposures on Landrum's Creek, in Marengo County, and on Pursley Creek, in Wilcox County, the uppermost 60 feet (viz, from the base of the Nanafalia marl down to the Coal Bluff lignite), while at Oak Hill (see below) we have a clear profile embracing at least 130 feet immediately overlying the Naheola marl. This would leave only about 10 feet of unknown beds at the top of our Naheola section, and it is altogether probable that the Pursley Creek and Oak Hill sections embrace the entire series.

The strata which make all the bluffs between the mouth of Beaver Creek and Naheola, as well as the upper part of the bluff at the last named place, consist, in descending order, of about 20 feet of coarse-grained micaceous sands, with projecting, indurated bowlders of sandstone (no fossils observed), with thin clay partings at intervals; below these, about 10 feet of strongly cross bedded sands, seen in the bluffs just below Tompkinsville, and underlying this to Naheola, laminated sandy clays traversed by layers of lighter colored, sandier, and indurated materials; no fossils observed. It is difficult to give a close estimate of the thickness of these last named beds, but it is not less than 50 or 60 feet, and may be 80.

The section (see Plate XVIII, Fig. 3, p. 167) represents the succession and quality of the beds along this stretch of the river.

The lowest of these gray sandy clays are seen at the top of the bluff at Naheola, a few miles above Tompkinsville, where they are underlaid by a marl, and black shaly clays at Naheola, as shown in the following section:

Section at Naheola, Tombigbee River, Sec. 31, *T.* 15, *R.* 1 *E.* (*Plate* XVIII, *Fig.* 3, *p.* 167.)

1. Laminated, gray, sandy clays, with two or three indurated ledges eight to ten inches thick, of lighter colored, sandier materials .... 18 to 20 feet.
2. Ledge of greensand, oxidized into a brown iron ore of irregular thickness, 3 to 6 inches.

3. Black, shaly, sandy clay .... 3 feet.
4. Ledge like No. 2, of irregular thickness .... 6 inches.
5. Greensand marl, the upper part indurated, forming a kind of limestone. Both the indurated marl and the limonite, or oxidized greensand above it, hold fossils, prominent among which are an *Arca*, a *Venus*, *Pectunculus Broderipii* Lea, *Turritella Mortoni* Con., *Cardita alticosta* Con., and *Venericardia rotunda* Lea, *Rostellaria trinodifera*, &c. All the fossils are badly preserved. Thickness of bed .... about 3 feet.[1]
6. Black, slaty clay like that occurring on the river above this point to Black Bluff .... 10 to 15 feet.

Half a mile or so below Naheola, just below Marengo Shoot, the marl bed No. 5 occurs at the water level, and at Kemp's Landing, a short distance above Naheola, the marl, with its overlying ferruginous concretions, is again seen.

On the Alabama River the Tertiary beds, corresponding to those just described in the vicinity of Tompkinsville, occur between Coal Bluff and Clifton, a distance, by the river, of 10 or 12 miles. On this river there are many interruptions in the continuity of the Tertiary bluffs, so that it would be impossible, from the exposures along the river alone, to get any clear idea of the stratigraphy. All this, however, is made good, as will be seen above, in the sections obtained at Oak Hill and on Pine Barren Creek, in eastern Wilcox County.

The Tertiary beds make the bluffs of the Alabama River at a few localities mentioned below and exhibited in Plate XVIII, Fig. 2, p. 167.

At Burford's Landing, NW. ¼ of Sec. 5, T. 11, R. 7 E., and just above it in Sec. 32, T. 12, R. 7 E., there are low bluffs of laminated and cross bedded sands, alternating with thin seams of gray clay.

At Walnnt Bluff, below the mouth of Turkey Creek, the banks are of light colored, yellowish, cross bedded sands, and above Turkey Creek a laminated, sandy clay like so much of the material occurring about Tompkinsville. These clays are devoid of fossils and continue up to Clifton, with very variable dip, the beds being sometimes horizontal, sometimes strongly inclined (nearly one foot in ten), but the average dip is much less, probably somewhere near one in two hundred. It thus becomes very difficult to sum up the thickness of these sandy clays, both because of variable dip and because the bluffs are not continuous.

At Clifton the bluff is 75 feet or more in height, the greater part of the slope being of drift sands, &c., while the Tertiary clays at the base of the hill are only about 10 feet in thickness.

[1] During the summer of 1886 this bed was more closely examined than in 1883, with the result of finding in its lower part a great number of the characteristic Matthews's Landing fossils. Wherever this bed has been exposed to the weather it crumbles down, liberating the shells exactly as at the last-named locality. In 1883 our attention was confined to the upper part of the Naheola bed, with its badly-preserved shells in a greensand matrix; and thus the identity of this bed with that at Matthews's Landing was not so clearly seen.

About one mile above Clifton, on the left bank of the river, there is a low bluff of black clays, which extends about a mile up the river. These clays have not been closely examined, but they appear quite similar to those better seen higher up, at the mouth of Dickson's Creek, where a bluish black, micaceous, sandy clay, holding many finely preserved fossils, forms the right bank of the river. This is the same bed as that which makes the top of the bluff at Matthews's Landing, a mile or two higher up the river, where we get the following good section of this important deposit:

(*a*) *Section at Matthews's Landing, Alabama River, northern part of Sec.* 12, *T.* 12, *R.* 6 *E.* (*Plate XVIII, Fig.* 2, *p.* 167.)

1. Bluish or greenish black, micaceous, clayey sand, with finely preserved fossils, very dark when wet, but becoming grayish blue on drying; crumbles upon exposed slopes, liberating the fossils, which lie in the crumbs thus produced. This is capped by an indurated, sandy, concretionary ledge.[1] The thickness of the marl deposit is .... about 5 to 6 feet.
2. Gray sands with a slightly yellowish cast, showing a great tendency to indurate into lens-shaped bowlders, 1 to 2 feet thick and 3 to 4 feet wide. The sands are also fossiliferous, but much less so than the preceding; the fossils are difficult to get out because of the hardness of the material .... 3 to 4 feet.
3. Bluish, micaceous, clayey sand, much like No. 1, but not holding all of its characteristic fossils. Where this stratum lies exposed to the sun and weather upon flat or nearly horizontal benches, it disintegrates, like No. 1, into crumbs, in which the liberated fossils lie loosely, but where it forms vertical bluffs, it is firm and compact and resembles black clay .... 7 to 8 feet.

This lowermost bed is sandy above and clayey below, and the material of the whole bluff might be better described as a bluish black, sandy clay, divided into two parts by a bed of calcareous sand, which reaches up into the upper clay bed and down into the lower by gradual transition. The beds which compose this bluff are seen along the river for a mile or more, and are approximately horizontal in position, since the river in this part of its course runs in the direction of the strike of the beds.

The Matthews's Landing marl bed is seen eastward of the Alabama River at very many places in Wilcox County, and it holds usually a number of well-preserved fossils. Near Mr. Clarence Jones's, 7 miles east of Camden, on the Allenton road, there are a good many exposures of this marl bed in the gullies, and we get a very fair section of some 30 feet of the underlying rock. At Oak Hill and in Dale's Branch (see below) we have other good outcrops of the marl. The consideration of this fine section, which includes also the underlying beds down to the base of the Tertiary, we shall leave till after the description of the occurrences along the two rivers.

[1] This is probably one of the glauconitic, concretion-forming sands which are so characteristic of the marl of Naheola.

(6) THE BLACK BLUFF SERIES.

This section has been named from its most characteristic exposure at Black Bluff, on the Tombigbee River, in Sec. 12, T. 16, R. 1 W., in Sumter County, which is as follows:

(*a*) *Section at Black Bluff, Tombigbee River.* (*Plate XVIII, Fig.* 3, *p.* 167.)

1.	Yellowish clay, which makes the basis of the Flatwoods, occupying top of bluff	about 20 to 25 feet.
2.	Black, slaty clay, fossiliferous	40 feet.
3.	Brownish shale or clay to water level	8 to 10 feet.

The black clay, No. 2, contains marine fossils, the most prominent among which are a little coral, an Arca, fragments of the shells of a large Nautilus, parts of crabs, &c.

The lower part of the bluff at this place is covered with singularly shaped concretionary masses of limonite. The surfaces of these concretions are marked off into rhomboidal plates, like the markings on an alligator skin. The shales or black clays are strongly calcareous, which accounts for the limy character of some of the soils derived from them in Marengo and Wilcox Counties.

In Sumter County a bed of lignite is found near the summit of the black clays, and just beneath the yellowish clays of the above section.

All the bluffs from Black Bluff down to Naheola, above described, are composed of a black clay in most respects similar to No. 2 of the above section.

The fossiliferous bed of Black Bluff may be seen at any of the exposures as far down the river as Griffin's Landing, 7 or 8 miles, nearly along the strike of the strata. Below Griffin's, down to Naheola, the black clay of the bluffs is quite hard and compact, breaking with conchoidal fracture and resembling very closely the black shale of the Devonian formation. No trace of a fossil could be detected in the black clay along this long stretch of the river. At Lewis's Lower Landing, Beckley's, Oakchia, Steiner's, Kemp's, and Naheola the clays are usually covered with the singular limonite concretions remarked upon at Black Bluff.

The distance across the strike of the rocks, from Black Bluff to Naheola, is about 7 or 8 miles, and through this distance the only Tertiary rocks which appear on the river banks are black clays. Upon the assumption that the dip of these rocks is uniformly about 30 feet to the mile, this would indicate a thickness of nearly 200 feet. But we have seen above that undulations are not rare in the Tertiary rocks, so that the actual thickness is probably very considerably less than 200 feet. The Bladen Springs boring (Plate XXI, column 4, p. 183), shows, according to our interpretation of it, only about 100 feet of black clays above the Rotten Limestone, and a part of this may belong to the Ripley group of the Cretaceous.

As to the equivalence of this black clay group, there is no doubt that it in part represents the Flatwoods group of Dr. Hilgard, because these Flatwoods, so well developed in Mississippi, extend down into Sumter County, in Alabama, and across it to the Tombigbee, and thence across Marengo to the Alabama, which they touch at Midway, a short distance below Prairie Bluff. So far as I am aware, they have not been identified in Wilcox County, although the fossiliferous stratum of the Black Bluff group is very characteristically developed across this county, as may be seen from the sections still to be given.

These Black Bluff clays in Sumter and Marengo Counties contain very little lime, and form Post-Oak Flatwoods with stiff clay soil, while east of the Alabama River they become more and more calcareous, and form the basis of the prairies in Wilcox County and eastward. Even in Marengo County the lower part of the Black Bluff clays is much more calcareous than the upper, and we find a narrow belt of black prairie land lying just north of the Post-Oak Flatwoods. This prairie soil merges by almost imperceptible gradations into the genuine Flatwoods.

7. THE MIDWAY SERIES.

Between Matthews's Landing, above described, and Midway there are no Tertiary rocks exposed along the banks of the Alabama River.

The bluff at Midway is half a mile or more in length, the dip of the strata quite variable, but very considerable, in places as much as one in thirty, and in some places the beds are nearly horizontal. At the lower end of the bluff appear black clays similar to those at Matthews's Landing or Black Bluff, a few feet only showing, and these apparently without fossils. These clays overlie about 10 feet of light colored argillaceous limestone, with projecting hard ledges. This limestone contains the large Nautilus (Enclimatoceras) which characterizes the lowermost Tertiary beds about Pine Barren Creek below mentioned, and it is no doubt identical with the Nautilus rock of eastern Wilcox.

This Nautilus rock has been recognized in that part of Wilcox County lying west of the Alabama River, and it has been traced thence across Marengo County to Moscow, on the Tombigbee River. Southward of the localities where it forms the surface appears always a strip of black prairie soils, derived from the disintegration of the calcareous clays (of Black Bluff group), which immediately overlie the Nautilus limestone, and southward still of this prairie belt lies the belt of Post-Oak Flatwoods, the soils of which come from the disintegration of the noncalcareous clays of the Black Bluff group. The Flatwoods belt, as has already been intimated, does not appear to extend beyond the Alabama River towards the east, while the prairie belt attains to greater and greater importance in that direction.

Midway is some 4 miles down the river from Prairie Bluff, where occurs the first outcrop of Cretaceous rocks on the Alabama.

Between these two points there are none but comparatively recent deposits along the river banks.

The position and character of the Tertiary rocks exposed at Midway may be seen on Plate XVIII, Fig. 2, p. 167.

THE OAK HILL AND PINE BARREN PROFILE.

This profile embraces the strata of the Naheola or Matthews's Landing, the Black Bluff, and the Midway sections above described, and gives us a continuous view of all the strata from just below the Coal Bluff lignite down to and including the uppermost beds of the Cretaceous. Our three lowest sections of the Lignitic might with propriety be classed together as the Oak Hill Pine Barren group.

About half a mile to three-quarters west of Oak Hill, in Sec. 16, T. 11, R. 10 E., in Wilcox County, the Allenton and Camden road descends a long hill, where at least 150 feet of the Tertiary strata are laid bare.

(*a*) *Section near Oak Hill, Wilcox County.* (*Plate XVIII, p.* 167.)

Red loam, pebbles, &c. of the Drift.

1. Cross bedded sands and thinly laminated clays, much decayed and difficult at times to distinguish from the overlying red loam ....25 feet.
2. Gray, cross bedded sands, alternating with thin laminæ of gray clay; general aspect of the whole, gray ....40 feet.
3. Bed of yellowish gray, cross bedded, and laminated sand ....18 inches.
4. Thinly bedded, gray clays, interstratified with thin ledges of cross bedded sands ....30 feet.
5. Sands 1 foot, clays 1 foot, sands 1 foot ....3 feet.
6. Gray clays, interstratified with cross bedded sands.......................6 feet.
7. Gray, cross bedded sands with very little clay .... 3 feet.
8. Gray clay breaking up into cuboidal blocks, interstratified with sandy ledges ....15 feet.
9. Black to gray micaceous sands, with the fossils of Matthews's Landing.....7 feet.
   This bed is darker at top and lighter colored at bottom. In Dale's Branch, close by, the same bed occurs with glauconite in part of it. It is quite possible that part of this bed may be identical with the Naheola marl. At other localities, near Oak Hill, this bed has a greater thickness, and the above may be taken as the lower limit. According to the observations of Mr. Johnson, in a well bored at W. W. McConnico's, the thickness goes even to 20 feet, thus approximating the thickness at Matthews's Landing.
10. Hard ledge of calcareous glauconitic sand .... 1 foot.
11. Yellowish, calcareous sands, with white lime concretions and one or two harder ledges .... 12 feet.
12. Glauconitic sands with indurated ledge at top .... 10 feet.
13. Sandy shales, with indurated ledge .... 5 feet.
14. Hard, yellowish, sandy limestone, with phosphatic nodules, appearing also in the Graveyard Hill section, No. 3 ....2 to 3 feet.

This bed is a very conspicuous feature in all this vicinity; it may be seen on the sides and summits of most of the low hills, where, breaking off in consequence of joint planes, it appears like a low stone wall running around the hills. From the locality above given to the Graveyard Hill this stratum can be followed with certainty, and appears as above stated in the accompanying section.

(*b*) *Section on Graveyard Hill.* (*Sec.* 5, *T.* 11, *R.* 10 *E.*)

1. Grayish white, calcareous sands, with small phosphatic nodules, characterized by an abundance of crustacean remains .... 5 feet.
2. Whitish, calcareous sands, with several harder ledges which shale off in weathering .... 20 feet.
3. Hard, yellowish, sandy limestone, containing small phosphatic nodules. This is the rock which forms the walls around all the low hills in the vicinity. 2 to 3 feet.
4. Yellowish, calcareous, clayey sand, with white lime concretions, becoming grayer in color and more clayey, and containing numerous fossils identical with those found at Black Bluff .... 15 feet.
5. Black, calcareous clays, yellowish gray on weathered surfaces, also containing the Black Bluff fossils, but less abundantly than the preceding bed. 20 feet or more.

This black clay and the overlying bed yield the prairie soils of this section of Wilcox County. These soils are exceedingly fertile, as may be seen by the fine crops which grow upon them and by the immense height of the weeds which spring up by the roadsides.

Graveyard Hill, like all the others in the vicinity, slopes off into the prairie fields which border Prairie and Pine Barren Creeks. In the lower parts of these fields we come always upon a ledge of rocks, decribed below, which forms the continuation of the section above given. Below this rocky ledge occur sands and sandy shales, which undoubtedly belong to the Cretaceous formation.

The whole thickness of the clays, &c., which form the prairies here is about 30 to 35 feet, so that what follows is only the direct continuation of the preceding section.

(*c*) *Section from base of Graveyard Hill to Pine Barren Creek.*

Black clays, weathering yellow, basis of prairies, No. 5 of the preceding section.

6. Hard, grayish white limestone, characterized by great numbers of a large *Nautilus* (*Enclimatoceras Ulrichi*), and hence known as the Nautilus Rock .. about 10 feet.
7. Calcareous sands forming basis of the black, sandy prairies of this vicinity .. 6 feet.
8. Hard, yellowish white, crystalline lime rock, sandy in places and filled with red specks, highly fossiliferous, containing *Turritella* in great numbers; also *Carditas*, a *Rostellaria*, *Ostrea*, and two or three species of coral. This is one of the most persistent of the lower Tertiary rocks towards the east .... 8 feet.
9. Yellowish, micaceous sands, with Cretaceous fossils .... 55 feet.
10. Bluish gray, calcareous sands, with two very prominent ledges 4 feet apart, and two or three smaller ledges. Thickness to water level below Palmer's Mill .... 15 feet.

These three sections are illustrated in Fig. 1 of Plate XVIII, p. 167.

It may be remembered that from the summit of the White Limestone down to the base of the Bell's Landing section of Lignitic, representing about 1,200 feet, our geological column is uninterrupted and is covered throughout by overlapping sections.

Below the Bell's Landing section occurs the first hiatus or break in this column, the first place where we have as yet been unable to connect two contiguous divisions by overlapping sections.

Immediately below the Coal Bluff lignite of the preceding section there is a second gap, the exact dimensions of which we have as yet not been able to ascertain. Making the highest estimate (based upon an assumed uniform dip of the strata of 30 feet to the mile), the thickness of the beds here concerned can hardly be more than 50 or 60 feet, for the missing beds should outcrop along the Tombigbee River between Nanafalia Landing and the mouth of Beaver Creek, a distance of 4 miles, corresponding to a thickness of 120 feet. We know, from exposures on Landrum's Creek and Pursley Creek, all the beds below the Nanafalia marl down to the lignite, 60 feet below, so that the missing beds would constitute the other half of this estimated 120 feet.

On the Alabama River, likewise, we see some ten feet of strata below the lignite, after which follows a barren stretch of river bank which shows no Tertiary beds at all for two or three miles.

In the Pine Barren profile, which gives so complete a view of the lower part of the Tertiary formation, the lignite is not seen in actual contact with the beds of this section, so that here, also, we have the gap unfilled. From the occurrence of the lignite, however, a short distance south of Oak Hill, which makes the summit of the Pine Barren section, the thickness of the beds involved in this gap is here also shown to be not very great, except upon the assumption of a very abrupt change in the dip of the strata, which is wholly unauthorized by any facts which have come under our observation.

Geologically below this gap, from the mouth of Beaver Creek, on the Tombigbee, to Black Bluff (up the river), there is an almost continuous exposure of Tertiary beds along the river banks, but there is difficulty in getting the exact thickness of the beds thus exposed.

On the Alabama River the exposures are much less continuous, and the thickness of the beds correspondingly more difficult to ascertain.

It is therefore fortunate that we have, in the Pine Barren region, a continuous section of 240 to 250 feet, embracing all the beds below the gap or hiatus named, down to the top of the Cretaceous formation.

This section is exposed at two localities, above given, viz: Along the Camden road, about half a mile west of Oak Hill, and at the Graveyard Hill in Sec. 8, T. 11, R. 10 E., the lower beds of Oak Hill appearing in the upper part of the Graveyard Hill. The lower portion of the section appears at the base of the latter hill and along the low grounds of Prairie Creek down to Palmer's mill on Pine Barren Creek. All the lower part of this section, up to the Dale Branch or Matthews's Landing marl, was very carefully worked out in 1883 by Mr. Johnson, and the section continued by estimates up to the Nanafalia beds, which appear at Eggville, in Sec. 22, T. 11, R. 10 E. To Mr. Johnson also belongs the whole credit of determining beyond doubt the exact limit between the Tertiary and Cretaceous rocks in eastern Wilcox.

He has shown that the Nautilus (Enclimatoceras) Rock, which had, up to 1883, been considered Cretaceous, overlies a crystalline limestone holding *Turritellas*, *Carditas*, a *Rostellaria*, and other Tertiary species. The measured section from Chambers Creek across Pine Barren Creek up to the summit of the Graveyard Hill profile (see Plate XVIII, Fig. 1, p. 167) was also made by him.

In the summer of 1885 these localities were visited by the present writer, when the measured part of Mr. Johnson's section up to the Dale Branch or Matthews's Landing marl was fully verified and extended by the addition of some 125 feet of strata exposed along the Camden road, near Oak Hill, and in direct superposition over the Dale Branch marl. Notwithstanding the 125 feet thus transferred from "estimated" to the firm ground of "measured" strata, there still remains, as above stated, a gap not covered by overlapping sections between the top of the Oak Hill section and the Coal Bluff lignite.

It would be manifestly a serious omission on our part not to speak in this connection of the observations of Prof. Alexander Winchell, made in 1856 in eastern Wilcox County.[1]

This author recognized as Tertiary, and described in sufficient detail to render their identification easy, several of the beds included in our Pine Barren sections below given, notably No. 3 of the Graveyard Hill and the underlying marls containing Black Bluff fossils, and also the Turritella rock which lies at the base of our Tertiary section, and he rightly extends the line between the Tertiary and Cretaceous to a point eight and a half miles north of Allenton.

These rocks he, however, places in the Buhrstone, and above his Buff Sand, which he considers the lowermost of the Tertiary rocks. By comparing our Nanafalia sections and Professor Winchell's description, it will be seen that his Buff Sand overlies (at Black's Bluff on the Alabama River) the beds with *Gryphæa thirsæ*, which at that time was generally considered a Cretaceous species. These beds we now know are some 300 feet above the top of the Cretaceous.

Notwithstanding some mistakes in fixing the relative positions of rocks observed at widely distant localities, mistakes which were probably unavoidable without long-continued observations, we find recorded in this pioneer work of Professor Winchell a host of sagacious observations which have been fully confirmed by those who have since gone over the same ground.

In this part of the Tertiary the variations in the thickness of the beds and the quality of the material as we go from west to east are more striking than in the overlying strata. Thus, on the Tombigbee River, near the base of the Tertiary, there is a great thickness of black, sandy clays (80 feet or more in one place, Black Bluff), which extend down the river for many miles, to Naheola, while on the Alabama the only rocks seen of this kind are at and near Matthews's Landing, which is near the top of the series; and in the Pine Barren section in eastern

[1] Proceedings Am. Assoc. Adv. Sci., Part II, pp. 87–89, 1856.

Wilcox County, where all the strata are shown, the whole thickness, including the Matthews's Landing marl, is not greater than 75 feet.

On account of these differences it becomes impossible, without further comparison, to correlate some of the beds of the Tombigbee section with those exposed at Oak Hill and on Pine Barren Creek.

In the vicinity of Palmer's Mill (Smith's bridge), on Pine Barren Creek, in Wilcox County, we have the lowermost of the Tertiary beds in direct contact with the uppermost of the Cretaceous. At this place the beds of the two formations appear to be strictly conformable with each other. Here, also, the lower Tertiary beds have a very striking resemblance in lithological characters to some of the Cretaceous beds; but the fossils, as Mr. Johnson has shown, leave no room for doubt as to the age of the beds.

This resemblance is most pronounced in the case of the shaly sandy beds of Graveyard Hill, which might easily be mistaken for similar beds occurring at Canton Landing and back of Prairie Bluff. The latter are of Ripley age, while the Graveyard Hill rock overlies sandy clays holding Black Bluff fossils. So, also, the Nautilus rock might well pass for Cretaceous, except that it overlies a limestone holding Turritellas, Carditas, and other fossils which Mr. Johnson has identified as Tertiary. No one can fail to be impressed with the similarity in general aspect, if not in the organic contents, of the contiguous beds of the two formations.

THE BLADEN SPRINGS BORING.

In the years 1884 and 1885 a boring was made at Bladen Springs, in Choctaw County, in search of petroleum. The carefully kept record was obtained from Captain Trowbridge, who had charge of the boring.

The surface rocks at the place of boring are either the lowermost of the Buhrstone or, more probably, the uppermost of the Hatchetigbee, the loose surface materials hiding the Tertiary rocks at the locality. The boring penetrated through the underlying Tertiary rocks, through the Ripley, and 125 feet (as we interpret it) into the Rotten Limestone of the Cretaceous. We have inserted this record, drawn to scale, in its proper place in the general section (see Plate XXI, column 4, p. 183), where it will be seen the thickness revealed by the boring corresponds very well with that established by our measurements. It is, however, difficult to correlate with any certainty the beds penetrated by the boring with the strata of the general section, since an accurate determination of the lithological and other characters of the beds from the loose and mingled materials brought up by the auger is manifestly impossible; still, we have felt warranted in several instances in pointing out the probable equivalences. In the lower part of the boring, especially, we think that the black or dark blue clays and clayey sands of the Black Bluff and Ripley sections are unmistakably shown, as is also the Rotten Limestone, although in the boring there appear only 17 feet of sands at base of the Ripley, while in some places, as at Prairie Bluff, the thickness is at least 60 feet.

In 1884, while the boring was still in progress, Mr. D. W. Langdon, jr., visited Bladen Springs, and, upon the authority of our much less perfect river section, predicted that the Rotten Limestone would be reached at 1,200 feet. In reality it was reached at 1,220 feet.

§5. SUMMARY OF THE LEADING FEATURES OF THE TERTIARY STRATA OF ALABAMA (PLATE XXI).

With a brief review of the distinguishing characteristics of the divisions of the Tertiary above made, we conclude this part of our subject.

The whole thickness of the strata of the Tertiary group of Alabama occurring in the vicinity of the two rivers is between 1,620 and 1,700 feet. This estimate is based upon actual measurement, except at one or two horizons, and even in these places we are able to give a close estimate of the thickness of the strata not measured.

We have adopted the following fourfold division of the Tertiary:

(1) The White Limestone,
(2) The Claiborne,
(3) The Buhrstone, and
(4) The Lignitic.

In all that follows, the strata are described in descending order.

(1) THE WHITE LIMESTONE.

This subdivision is calcareous throughout, but the lowermost 60 feet are more argillaceous than the rest. The minimum thickness is 350 feet, of which the uppermost 150 feet consist of a tolerably pure but somewhat silicious limestone, filled with coral masses. The next succeeding 140 feet or more are made up of a soft, white limestone, often quite pure and filled with *Orbitoides Mantelli.* The lowermost 50 feet are of impure, argillaceous limestone, which in disintegrating yields a black, calcareous soil similar to that derived from the Rotten Limestone of the Cretaceous. This lower portion of the White Limestone surpasses the others in the variety of its fossil contents.

(2) THE CLAIBORNE.

The thickness is 140 to 145 feet, the materials are sands and clays, which are generally calcareous and often glauconitic. Near the top of the subdivision is a bed of glauconitic sand 15 to 17 feet in thickness, filled with shells in a perfect state of preservation. The sandy clays forming the lower 50 feet are likewise filled with a great variety of shells in a good state of preservation. The intervening calcareous clays and calcareous sands are distinguished by the great numbers of shells of *Ostrea sellæformis* which they hold, as well as by the comparative rarity of other forms.

(3) THE BUHRSTONE.

The minimum thickness of this formation is 300 feet; the materials are almost altogether aluminous and silicious, consisting of aluminous sandstones, claystones, and quartzitic sandstones, with occasional thin beds of glauconitic sand. The few fossils which have been obtained from this division are mostly in the form of casts. They do not appear to differ specifically from those of the overlying division.

(4) THE LIGNITIC.

This is the most massive of the subdivisions of the Tertiary, having a thickness which can hardly be less than 900 feet. It also presents a greater variety in mineral composition, as well as in fossils, than the other divisions. In the most general terms, the Lignitic strata are cross bedded sands, thin bedded or laminated sands, laminated clays and clayey sands, and beds of lignite, as well as the lignitic matter which merely colors the sands and clays. With these are found interbedded, at several horizons, strata containing marine fossils. For the sake of greater convenience and clearness of description we present the Lignitic in seven sections, each of which is characterized by one or more beds of marine fossils included in it. These sections are as follows:

(*a*) *The Hatchetigbee section.*—This section is 175 feet in thickness, made up of sandy clays of prevailing brown or purplish color, containing three or four beds of marine fossils in the uppermost 75 feet, and of somewhat similar purplish brown, sandy clays nearly devoid of marine fossils in the lower 100 feet. All these brown, sandy clays become much lighter colored upon drying and exposure to the weather.

(*b*) *The Wood's Bluff or Bashi section.*—This is 80 to 85 feet in thickness. The uppermost 30 feet of the section consist of dark brown clays passing into a greensand, which holds a great variety of finely preserved marine shells. Below this greensand marl are gray, sandy clays, with four or five thin beds of lignite within the first 25 feet, succeeded by about 30 feet of cross bedded sands, with a two foot seam of lignite at the base.

(*c*) *The Bell's Landing section.*—This is 140 feet in thickness, and includes two important marine beds, and a third, quite small and apparently unimportant. These fossiliferous beds are interstratified with yellowish sands in the upper and rather heavy bedded, sandy clays in the lower part of the section. The upper marine bed, called the Bell's Landing marl, is about ten feet in thickness and has 40 feet of sandy strata above it. The middle bed is called the Gregg's Landing marl, and it is twenty to twenty-five feet below the preceding; it is about five feet in thickness. The lowermost of the fossiliferous beds of this section is only about one foot in thickness and lies about fifty feet below the Gregg's Landing bed. It is highly glauconitic, but does not contain any great variety of fossils. The Bell's Landing marl is distinguished from all others in Alabama by the great size of the shells which it contains.

(*d*) *The Nanafalia and Coal Bluff section.*—The strata of this section are 200 feet in thickness and consist of about fifty feet of gray sandy clays at top, which show a tendency to indurate into tolerably firm rocks resembling very closely some of the strata of the Buhrstone. Below this, about eighty feet of sandy beds, often strongly glauconitic, characterized throughout by shells of a small oyster, *Gryphæa thirsæ.* Near the base of this sandy division there is a bed about twenty feet thick, literally packed with these shells. Below the *Gryphæa thirsæ* beds follow some seventy feet of cross bedded sands, glauconitic and apparently devoid of fossils, including, about ten feet from the base of the section, a bed of lignite which varies in thickness from four to seven feet.

(*e*) *The Naheola and Matthews's Landing section.*—It is difficult to give the precise thickness of this section, since it varies on the two rivers. We have placed it at one hundred and thirty to one hundred and fifty feet; the strata are gray, sandy clays in the main, alternating with cross bedded sand. The beds of dark, sandy, and glauconitic clay, containing marine fossils, lie at the base of the section. At Naheola on the Tombigbee the upper and more glauconitic part of the bed is most prominent, while at Matthews's Landing on the Alabama, the lower part of the bed, dark gray sandy clay forms the bluff.

(*f*) *The Black Bluff section.*—Here again we have difficulty in determining the exact thickness, since on the Tombigbee the strata of this section are spread over an extent of surface which would, with uniform dip, correspond to a thickness of over two hundred feet, while on the Alabama, and more particularly inland in the eastern part of Wilcox County, the thickness is not greater than thirty-five or forty feet. Since 80 feet of these beds are seen in superposition at one locality (Black Bluff), we think that the maximum thickness cannot be less than one hundred feet. The characteristic strata which compose nearly the whole of this section are black or very dark brown clays, which are in part fossiliferous.

(*g*) *The Midway or Pine Barren section.*—Thickness, 25 feet. The strata are: a white, argillaceous limestone holding a large nautilus, which is characteristic of the horizon, 10 feet; calcareous sands and a yellowish, crystalline limestone, with Turritellas, Carditas, and corals, the sands 6 feet, the limestone 8 or 9 feet. This section is best seen in eastern Wilcox County on Pine Barren Creek, but the upper or Nautilus rock occurs at Midway, on the Alabama River, and westward across Marengo County. No exposure was noticed on the Tombigbee, but it will probably be found a short distance below Moscow.

II. CRETACEOUS STRATA.

The Cretaceous formation in Alabama exhibits three well marked divisions, which, in descending order, are as follows:

First. A series of yellow sands, dark gray or bluish, sandy, micaceous clays, impure limestone, and sands again, in all between two and three hundred feet in thickness. This has been called the Ripley formation by Hilgard, and the name is retained for Alabama.

Second. An impure, argillaceous limestone of tolerably uniform composition and about one thousand feet in thickness, known as the Rotten Limestone.

Third. A series of laminated sands and sandy clays at least three hundred feet in thickness which has been named the Eutaw formation.

All these strata, especially the calcareous parts, are more or less perfectly exhibited in the bluffs of the two rivers.

It will be seen below that we have not as yet been able to construct the column of strata of this formation with as great a degree of completeness as has been done for the Tertiary, but this want of completeness is in the figures showing the thicknesses of the several strata rather than in the succession and quality of these beds.

§1. THE RIPLEY FORMATION.

The character of the uppermost beds of this formation immediately underlying the Tertiary was first clearly determined by Mr. Johnson in the Pine Barren section, in the eastern part of Wilcox County, already given above. These uppermost beds were afterwards traced by him westward to the Alabama River and eastward to Clayton and Eufaula. The relation of the Bridgeport horizon to the yellow sands was also first determined by him. In 1885 the strata connecting the Bridgeport section with the Prairie Bluff section were determined by Mr. Langdon and myself, and it is believed that we now have the complete section of the Ripley strata along the rivers, except that the actual contact with the Rotten Limestone of the sands forming the lower part of Prairie Bluff, has not come under observation. The uppermost beds of this formation were also examined in 1885 by Mr. Langdon and myself in Marengo County, south of Dayton, as described below.

The strata of the Ripley formation, according to the investigations above alluded to, are as follows:

First. Fifty-five feet of yellow sands, not recognized on the Tombigbee River, but constituting the upper part of the bluff at Bridgeport, on the Alabama River, and much better developed in the hills immediately back of the bluff. From here they may be traced across the country for a great distance eastward. Mr. Johnson has probably identified this sand at Clayton, in Barbour County, where it constitutes the basis of the fields on the south side of Barbour Creek. In this sand on the road between Eufaula and Clayton were found decayed shells of a small oyster, and with them *Exogyra costata* Say in a pretty good state of preservation. The same oyster, without the Exogyra, was seen in the eastern part of Wilcox County, on Prairie Creek.

Second. About one hundred feet of bluish, micaceous, sandy clays, somewhat calcareous, marked at intervals of ten or fifteen feet throughout the whole thickness by the occurrence of indurated ledges, usually of rather sandier texture. These ledges appear occasionally as shaly sandstones of very little hardness, flaking off readily into sheets under the influence of the weather. Our observations in the Canton Bend and in the hills between Prairie Bluff and Rehoboth, and also westward towards Linden, in Marengo County, and eastward in Dallas and Wilcox Counties, have shown that these sandy clays, where they lie high above the drainage and well exposed to the action of the weather, lose altogether their bluish color and appear in all shades of yellowish gray. This difference in color, depending upon the degree of oxidation of certain constituents of the strata, especially the iron bearing materials, has not unfrequently been observed in the strata both of the Tertiary and of the Cretaceous groups. The most striking instance of this sort is to be seen at Prairie Bluff, where the sands forming the lower part of the bluff exhibit a dark blue, almost black color near the water's edge, while the same stratum is seen to be a white sand where it outcrops at the top of the bluff higher up the river.

Later observations in 1886 by Mr. Langdon and myself have shown clearly that the differences in these yellow sands and bluish micaceous sandy clays arise merely from different degrees of oxidation. In some of the outcrops observed by us, e. g., in Little Texas, Butler County, and in Lowndes County, bluish, micaceous sands, identical in appearance with those making the lower part of the Bridgeport Bluff, are seen along the banks of Cedar Creek directly underlying the Nautilus rock and Turritella limestone which lie at the base of the Tertiary. The same thing may likewise be seen in the upper part of Marengo County, where it has been found impossible to separate the yellow sands from the bluish, sandy clays.

Third. Calcareous beds some twenty feet in thickness, holding great numbers of Cretaceous fossils, some well preserved, others only in casts, which in every case appear to be very strongly phosphatic. One of the layers of this section is a sandy limestone containing a large percentage of phosphoric acid (see details below). These beds appear in a small bluff at the mouth of Tear Up Creek, above Bridgeport, which has been studied by Mr. Johnson; also in localities recently examined by Mr. Langdon and myself, viz, in the bluff at the old Canton landing; on Foster's Creek, in Gee's Bend; near Snow Hill, Wilcox County, and

Minter, Carlowville, and Richmond, in Dallas County; the four last named localities were also visited by Mr. Johnson in 1883.

Fourth. From sixty to one hundred feet of sand, with indurated bands of calcareous sand passing through it. These hard, projecting, sandy layers are usually filled with the shells of large *Exogyra costata* Say and *Gryphœa mutabilis* Mort. The thickness of these sandy beds, which apparently immediately overlie the Rotten Limestone, has not yet been accurately determined, but we see some fifty feet or more of them at Prairie Bluff.

Prof. A. Winchell[1] considers the rock at the base of Prairie Bluff as the topmost of the Rotten Limestone formation, and if this supposition be correct we have the complete section of the Ripley formation. We were, however, unable to satisfy ourselves of the identity of any of the rocks at Prairie Bluff with the Rotten Limestone, though we are convinced that the top of the latter formation does not lie far below the lowermost of the Prairie Bluff strata, since Rotten Limestone appears in the hills near the river a short distance above Prairie Bluff.

SECTIONS OF THE RIPLEY FORMATION.

In the subjoined sections and in the figures on Plate XIX we have given in detail the characters of the strata making up these subdivisions of the Ripley formation. These sections are given in descending order, that is, beginning with that one which shows the uppermost of the strata, and in the figures of Plate XIX the equivalence of the several sections is indicated as nearly as it can be made out. In most cases the equivalence is very clearly seen.

Near Palmer's Mill, on Pine Barren Creek, in the eastern part of Wilcox County, Mr. Johnson in 1883 obtained the following satisfactory section showing the actual contact of Tertiary and Cretaceous strata. The locality was also visited by myself in 1885, as mentioned above.

(*a*) *Pine Barren section.* (*Plate XVIII, Fig.* 1, *p.* 167, *and Plate XIX, Fig.* 1, *p.* 171.)

1. Hard, grayish white limestone, characterized by great numbers of a large *Nautilus* (*Enclimatoceras Ulrichi* White), and hence designated by us as the "Nautilus Rock" .... 10 feet.
2. Calcareous sands forming the basis of the sandy prairies of the vicinity ..... 6 feet.
3. Hard, yellowish white, crystalline limestone, sandy in places and filled with red specks. Highly fossiliferous, a *Turritella*, closely related to *T. Mortoni*, being the chief fossil, along with a *Cardita*, two or three species of coral, and numerous oysters. This is one of the most persistent of the lower Tertiary rocks towards the eastern part of the State .... 8 feet.
4. Yellowish, micaceous sands, with Cretaceous fossils .... 55 feet.
5. Bluish gray, calcareous sands, with one or two very prominent hard ledges 4 feet apart, and two or three smaller ledges of similar character. Thickness seen at Palmer's Mill .... 15 feet.

[1] Proc. Am. Assoc. Adv. Sci., Vol. X, Part II, p. 91, 1856.

In this section the lowest Tertiary bed is No. 3 and the uppermost Cretaceous No. 4, as is very clearly shown by the included fossils of each, and as the two are in direct contact there can be no question of their relations.

Bridgeport.—On the way from Camden to Bridgeport the road descends a long clay hill, in which the clays of the Black Bluff horizon form the surface (see Pine Barren section, under the Tertiary, Plate XVIII). At the foot of the hill is the yellowish white, crystalline limestone, No. 3 of the preceding section, and below that yellow, micaceous sands to the landing. At the Bridgeport Landing these yellow sands form the upper part of the bluff, though their whole thickness is not seen in the immediate bluff of the river, but may be seen at the base of the hills immediately back of the river bluff.

The section at Bridgeport is as follows:

(*b*) *Section at Bridgeport Bluff, Alabama River.* (*Plate XIX, Fig.* 2, *p.* 171.)

1. Yellowish, clayey sands, probably reworked .... 10 feet.
2. Coarse, yellow sands .... 10 feet.
3. Laminated, gray clays .... 1 foot.
4. Projecting ledge of sandy clay of dark gray color .... 1 foot.
5. Dark gray, nearly black, sandy, and in some parts micaceous clays, in beds about 3 feet thick, separated by hard projecting ledges of sandier material and of lighter color and averaging 8 to 10 inches in thickness .... 22 feet.
6. Projecting ledge of light colored, sandy material, forming a pretty firm sandstone. This ledge breaks off in cuboidal blocks, which roll down and cover the slope below it .... 18 inches.
7. Dark gray clays .... 3 feet.
8. Projecting sandy ledge .... 1 foot.
9. Dark, sandy clays, with two or more harder ledges, down to the water level .. 10 feet.

The ledge No. 6 makes a very prominent mark along the face of the bluff, as it is more persistent, harder, and more rock-like than the others. No distinct and well defined fossils were found at this place in the micaceous clays, but in one or two of the harder ledges below No. 6 were found a few friable shells of Ostrea, one *Pecten quinquecostatus* Sow., and a few indistinct impressions of other forms, two of which, if Mr. Johnson is not mistaken as to their characteristics, he was enabled at Eufaula to identify as *Nautilus Dekayi* Mort, and *Placuna scabra* Mort.

Canton Landing.—A short distance below Bridgeport there is an exposure of Cretaceous rocks at the old Canton Landing and in the hill which comes down nearly to the river bluff at that place. This locality was examined by Mr. Langdon and myself in the summer of 1885. It presents the following:

(*c*) *Section at the old Canton Landing, Alabama River.* (*Plate XIX, Fig.* 3, *p.* 171.)

1. Yellowish gray, calcareous, clayey sands in beds 3 to 5 feet thick, separated by harder projecting ledges of somewhat sandier material averaging perhaps a foot in thickness .... 100 feet.

   The hard ledges named have a tendency to flake off on weathering into sheets as wide as the hand. They often also break off into fragments which are of very irregular shape and of rough surface. All these beds make up the hill, appearing at intervals through the overlying débris, but no continuous section is exposed. In some places the clayey sands lying immediately below one of the hard ledges have the bluish black color which characterizes the whole of the lower part of the Bridgeport bluff, with which there seems to be very little doubt that these are identical.

2. Yellowish, calcareous, sandy clays like the preceding, with a hard, sandier ledge above and below, making top of immediate bluff of the river..............10 feet.
3. Bluish, micaceous clays, the counterpart of those at Bridgeport, with two or more indurated ledges..12 feet.
4. Light gray, calcareous sands, with an indurated ledge of nearly pure sandstone at the base. The upper part of this bed is disposed to form rough, indurated masses holding phosphatized shell casts and phosphatic nodules...................6 feet.
5. Bluish gray, sandy clays, much more clayey than the preceding bed, about 5 feet in thickness, passing below into a more sandy bed 3 feet thick, containing numerous shell casts and nodules..8 feet.
6. Bluish, argillaceous limestone, containing great numbers of *Exogyra costata* Say, *Gryphæa mutabilis* Mort., and phosphatized shell casts.................... 3 feet.
7. Bluish, calcareous sands containing many well preserved shells, prominent among which is a *Spondylus*, *Pecten quinquecostatus* Sow., together with phosphatized casts of *Nautilus Dekayi* Mort., turreted shells, &c. This bed goes down to water level...3 feet.

At this bluff there is a very distinctly defined fault, where some fifty yards of the face of the bluff have slipped down a distance of five or six feet. The lines of fault on each side of this piece are marked by broken fragments of the beds or so-called "fault rock" (see Fig. 1, p. 132).

In this section, beds Nos. 2 and 3 are entirely similar in mineral composition and appearance to part of the Bridgeport bluff, and the overlying beds are also similar in composition, though of much lighter yellowish color, which is in all probability due to their greater degree of exposure to the oxidizing action of the weather. This bluff is only a mile or so distant across the strike of the rocks from Bridgeport, and there seems to be no reason for doubting that the bluish, micaceous clays and sands of Bridgeport are identical with the yellowish, sandy clays with indurated ledges which form the upper members of the Canton section. The beds numbered from 4 down we consider the same as those appearing at the top of the bluff at Prairie Bluff, to be presently described.

Foster's Creek.—The beds above described at Canton landing continue across the bend lying to the east and known as Gee's Bend, where they may be seen in the banks of Foster's Creek, on John H. Pettway's land.

(*d*) *Section on Foster's Creek.* (*Plate XIX, Fig.* 4, *p.* 171.)

1. Yellowish, calcareous, clay soil supporting a vegetation almost exclusively of cedars.
2. Dark gray, sandy, micaceous clays like those at Bridgeport landing, in beds of 5 to 6 feet thickness, separated by harder ledges of lighter colored and sandier material..30 feet.

   In the lower part of these beds were collected by myself some of the small Gryphæas, probably *Gryphæa vomer* Mort., first seen by us at Moscow, on the Tombigbee River.

3. Cream colored, impure limestone, glauconitic, holding some phosphatized shell casts .... 5 feet.
4. Ledge of coarse grained, calcareous sandstone .... 2 feet.
5. Bluish, clayey limestone, no fossils at the top, but filled in its lower parts with fossils which are in many instances only the phosphatized casts of the shell. Among the forms collected here we have identified the following: A *Spondylus*, same as that at Canton; *Gryphæa mutabilis* Mort., *Exogyra costata* Say, *Scaphites Conradi* Mort., *Nautilus Dekayi* Mort., &c .... 20 feet.
6. Dark brown, crystalline, phosphatic limestone .... 1 foot.
7. Yellowish white limestone down to water .... 1 foot.

In another part of the same plantation, on what is called Livingston Hill, the phosphatic limestone and accompanying rocks may again be seen. From the geographical position of the beds represented in the above section, there is every reason to think that they underlie the visible portion of the bluff at Bridgeport. The identity of the lower 20 feet or so of this and of the Canton section is sufficiently clear.

Tear Up Creek.—A few miles above Bridgeport, at the mouth of Tear Up Creek, Mr. Johnson obtained in 1883 a good section of the beds underlying those of the Bridgeport bluff and was able to trace the connection between the two.

(*e*) *Section at the mouth of Tear Up Creek.* (*Plate XIX, Fig.* 5, *p.* 171.)

1. Ferruginous, sandy marl full of Cretaceous fossils .... 3 feet.
2. Very firm, white limestone, no fossils seen .... 6 feet.
3. Firm limestone, with a few fossils .... 2 feet.
4. Sandy, calcareous beds, with fine *Ammonites* .... 4 feet.
5. Sandy, indurated limestone forming a broad ledge .... 1 to 2 feet.
6. Argillaceous limestone, with *Exogyra costata*, &c .... 8 feet.

The fossils of this bluff are plainly Cretaceous and resemble the finest of those occurring at Prairie Bluff. There is good reason for thinking that most of the fine specimens of the old Tuomey collection labeled "Bridgeport" have come from this locality (L. C. J.). The dark, micaceous clays of Bridgeport are easily recognized in the bed of Tear Up Creek between its mouth and its source under McNeill Mountain, as shown in Plate XIX, Fig. 5. As has already been pointed out, they are seen also in the banks of Pine Barren Creek, at Palmer's Mill. The fossiliferous portion of this bluff is undoubtedly equivalent to the fossiliferous beds occurring on Foster's Creek and at Canton Landing, above described, as also to those at the top of the Prairie Bluff, given below.

During the summer of 1886 Mr. Langdon and myself went in a skiff from Bridgeport to Prairie Bluff and saw no Rotten Limestone in any of the river bluffs, all these exposures representing the Bridgeport and Prairie Bluff strata only.

The principal exposures are the following: From Bridgeport the bluff extends about a mile down the river, and then after a barren stretch of two miles or more come the bluffs at the old Canton Landing described above, and below that the following:

(f) Section four or five miles below the old Canton Landing, Alabama River.

1. Sandstone ledge, fossiliferous, yellowish, and wearing into very irregular shapes, 1 to 1½ feet.
2. Highly fossiliferous, blue sand, becoming light gray below, containing *Ostrea larva*, *Exogyra costata*, *Turritella*, &c., very much resembling specimens from Eufaula.......... 5 to 6 feet.

Two hundred yards down the river other underlying beds are to be seen, as follows:

3. Sandstone ledge.......... 1 to 1½ feet.
4. Light colored sands, no fossils observed.......... 20 feet.

At an old abandoned landing just above Mixon's we get a very good section, as follows:

(g) Section near Mixon's.

1. Yellow sands making top of the bluff back of the immediate river bank, at least 30 feet exposed, but apparently forming the whole slope of 60 feet.......... 60 feet.
2. Blue, micaceous sands, with the same fossils as No. 2 of the preceding section, 6 to 8 feet.
3. Sandstone ledge.......... 1 to 1½ feet.
4. Light colored sands.......... 30 feet.
5. Hard sandstone ledge.......... 1 foot.
6. Blue, micaceous, sandy clays (few fossils).......... 10 feet.

A mile or two above Prairie Bluff there is a high bluff very much resembling that at the former locality. The strata are undulating, at the lower end of the bluff dipping down stream at the rate of 1 foot in 10, at the upper end lying nearly horizontal. The beds here are as follows:

(h) Section one mile above Prairie Bluff (Rocky Bluff), Alabama River.

1. In the cliff just back of the immediate bluff of the river there are about 40 feet of strata, light colored, calcareous sands, with indurated bands, as at Prairie Bluff.......... 40 feet.
2. Dark blue, sandy, micaceous clays, with a few fossils, chiefly Anomias.......... 20 feet.
3. Hard, yellow, sandy ledge, the broken pieces of which cover the slope of No. 4. It dips below water at the lower end of the bluff.......... 1 foot.
4. Grayish, fossiliferous sands, full of shells of *Pecten quinquecostatus*, which, however, are very friable.......... 8 feet.
5. Hard, yellowish, sandy ledge like No. 3.......... 1 foot.
6. Bluish gray, calcareous sands, with some fossils.......... 10 feet.

In all these bluffs the indurated sandstone ledges are of very irregular thickness and lateral extent and are probably only local deposits in the regular strata or local indurations of the sands.

Prairie Bluff.—This locality has been visited by Professor Tuomey, Professor Winchell, and others.[1] We have very little to add to their descriptions, except to point out the probable equivalences of the beds

[1] Described in First Bien. Rep. Geol. Ala., 1850, and Proc. Am. Assoc. Adv. Sci., Vol. X, Part II, p. 90, 1856.

occurring here with those just described. The bluff shows the following:

(*i*) *Section at Prairie Bluff, Alabama River.* (*Plate XIX, Fig.* 6, *p.* 171.)

1. Bluish limestone containing *Exogyra costata, Gryphæa mutabilis*, and great numbers of shell casts, which are mostly phosphatized. This limestone has two hard ledges passing through it. Professor Winchell gives 6 feet as the thickness of this limestone, but we include with it some overlying fossiliferous, sandy beds and make the thickness[1] .... 20 feet.

   Among the forms recognized in casts or otherwise from this stratum may be mentioned *Gryphæa convexa, Placuna scabra, Scaphites Conradi*, and *Nautilus Dekayi*. Besides these there are very many other turreted shells not fully identified. The association is the same as at Canton Landing, Foster's Creek, Tear Up Creek, &c.
2. Sandy beds, with bands of hardened sand passing through them; these harder ledges are usually fossiliferous, the commonest forms being *Exogyra costata* and *Gryphæa mutabilis*. These sands form all the lower part of the bluff..50 to 60 feet.

The upper sandy beds contain great numbers of *Ostrea falcata* Mort. The lower beds are of dark blue color, but they bleach out to nearly white sand where they come to the top of the bluff, a short distance up the river from the landing.

The dip of the strata at Prairie Bluff is very considerable, being as high as 300 to 350 feet to the mile. Between Prairie Bluff and Rehoboth the hills are formed of the strata overlying the limestone No. 1 of the section. These are yellowish, micaceous sands, in beds 5 to 6 feet in thickness, separated by sandy ledges, and in all respects similar to the upper 100 feet of the section at the old Canton Landing. In structure and general appearance they are like the dark colored, sandy clays of Bridgeport, but the color is much lighter, due, as we believe, to the more complete oxidation of the materials. In these sands there are, in some localities, great numbers of irregular calcareous concretions. All the shell casts occurring in the upper calcareous part of Prairie Bluff,

[1] In the summer of 1886 Mr. Langdon gave this bluff a closer examination. He subdivides that part of No. 1, immediately above the sands, as follows:

1. Shaly, calcareous sands, yellowish gray on weathered surface; contains a seam of phosphatic greensand at the top, immediately underneath the warehouse..4 feet.
2. Pseudo-Rotten Limestone, i. e., calcareous clay ....3 feet.
3. Shell conglomerate ....3 to 4 feet.
4. Light colored sands &c., No. 2 of the section in the text above.

Mr. Langdon makes the additional important observation here that the very rapid dip down stream is confined to the sandy strata No. 4, and is not shared by Nos. 2 and 3, which half a mile below the warehouse are only about ten feet nearer water level than at the warehouse, while the uppermost indurated ledge in the sands No. 4 dips below the water within a distance of 200 yards, a descent of some 40 or 50 feet. This observation would show an unconformity between the calcareous and the sandy parts of the strata at Prairie Bluff.

Our discovery of the phosphatic greensand here fixes its position in the geological scale. The bed at Coatopa, in Sumter County, seems to have a similar position, but it appears now probable that there are at least two of these phosphatic greensands in the Ripley formation.

together with the calcareous sandstone which is included in the limestone, are very strongly phosphatic, as has been shown by the recent investigations of the Geological Survey of Alabama.

In the foregoing sections the calcareous and fossiliferous parts, about 20 feet in thickness, appearing at the mouth of Tear Up Creek, on Foster's Creek, at the base of the Canton Bluff, and at the top of Prairie Bluff are, we think, the same; for, though there seem to be slight differences in the succession of the different materials which constitute these beds, these differences are in many cases due to differences in the groupings. The general impression made upon the mind in inspecting them is that they are identical; they contain the same fossils and in the same state of preservation; they hold strata of sandy limestone, or, rather, of calcareous sandstone which is very highly phosphatic; in some instances, where analyses have been made, they hold from 10 to 15 per cent. of phosphoric acid. In all cases they are overlaid by micaceous, clayey sands, traversed by indurated bands of similar, but rather more sandy, material. These overlying beds differ sometimes conspicuously in color, which at Bridgeport, near the water level, is a dark blue, while on the hills back of the old Canton Landing and back of Prairie Bluff the color is a yellowish gray. This difference can be accounted for by differences in degree of oxidation, for where the color at the surface is yellow we have noticed that upon digging into the beds a few inches the dark color may be seen in most cases. In our minds there is no doubt of these equivalences. Prof. A. Winchell is of opinion that the lower beds of the Prairie Bluff section belong to the Rotten Limestone, but we were unable to discover anything there which we could identify with the Rotten Limestone. There is no doubt, however, for reasons above given, that the Rotten Limestone is not far below the lowest of the Prairie Bluff sands.

Moscow.—On the Tombigbee River we have seen only one locality where the strata of this division of the Cretaceous appear, and that is at Moscow, a mile or two above Black Bluff, already described.

(*j*) *Section exposed at Moscow and below, Tombigbee River.* (*Plate XIX, Fig.* 7, *p.* 171.)

1. Black, shaly clay, devoid of fossils, but containing a few rounded, concretionary masses like fucoids. This stratum appears below the Moscow Landing and in the principal stratum at the mouth of Sucarnochee River. Thin layers of calcite lie upon this clay, having been weathered out from between the layers of clay, in all .... 6 to 8 feet.
2. Dark blue, shaly, argillaceous limestone, with thin, projecting ledges of harder material, 10 to 12 feet thick near Moscow, but down the river thickening up to .... 20 or 30 feet.
3. Thin ledge made up almost entirely of the shells of the small Gryphæa (*Gryphæa vomer*), noticed also at Foster's Creek, in Gee's Bend .... 8 to 12 inches.
4. Hard, white, argillaceous limestone, with *Exogyra costata*, *Gryphæa mutabilis*, &c .... 10 feet.[1]

[1] Near the landing this bed is not less than 25 feet.—E. A. S.

This stratum is indurated near the top, forming a hard ledge which is highly fossiliferous, containing Exogyra, Gryphæa, *Nautilus Dekayi*, Baculites, and univalve shells in phosphatized casts. Many of these casts are covered with little lumps of reddish, phosphatic, clayey material, which has replaced the whole of the original matter of the shells. Casts of this kind have been noticed in the strata of this horizon all across the State to Barbour County and seem to be quite characteristic.

In this argillaceous limestone there is, near the top, a very irregular, hard ledge consisting in the main of comminuted shells embedded in a sandy matrix. This ledge is very variable in thickness, ranging from a mere line up to 10 feet, and is not conformable with the rest of the strata, but appears to form irregular concretionary or segregative masses in the limestone. It contains a considerable percentage of phosphoric acid. A similar phosphatic sandy bed appears at top of Prairie Bluff, at the base of the Canton Bluff, and in the bank of Foster's Creek, above described.

The dip of the strata at Moscow is very rapid down the stream, and at the same time irregular, being in places as much as 350 feet to the mile, in which respect it agrees with the dip at Prairie Bluff. It is to be remarked that the dip of the Tertiary beds nearest to these two sections, viz, Black Bluff on the Tombigbee and at Midway and at Matthews's Landing on the Alabama, is very much less, being only about thirty to thirty-five feet to the mile. The dip of the Ripley beds, indeed, especially near the top, seems to be considerably greater than that of the underlying Rotten Limestone and other Cretaceous strata.

In the summer of 1886 Mr. Langdon and myself made a more careful examination of the bluffs between Moscow and the cut off, just above the mouth of Sucarnochee Creek, a distance of a mile or two. We found the strata not only strongly undulating, but in six or eight places very distinctly faulted, with a displacement of perhaps ten feet maximum.

Good photographs were obtained of two of these faults, and diagrams were made of several others. A very careful measurement of the thicknesses of the several strata exposed here confirms the estimates above given in the Moscow section, except that the black clays may be a little thicker, and the white, argillaceous limestone, No. 4, is at least 25 feet thick at the landing. Our former measurement was made a short distance below, where only 10 feet of it were seen.

The pockets of cross bedded sandstone which are noted as occurring at irregular intervals in this limestone are of very limited extent and of varying thickness. In one or two instances they have been broken by the faults above noted. (See Plate X, p. 133.)

That which we find most difficult of explanation at Moscow is the passage from the undoubted Ripley limestone, which appears to be the same in horizon with the beds at the old Canton Landing, in Gee's Bend, at the mouth of Tear Up Creek, &c., to the black clays of the Black

Bluff section (Tertiary), without any show of the Bridgeport sandy clays and the Nautilus and the Turritella rocks. And as the black clays and the Cretaceous limestone are in actual contact, visible to the eye, we cannot explain the failure of these beds to appear here, by interruptions in the continuity of the river bluffs. It is possible that the black clays may be the representatives of the Bridgeport beds, but it is not probable, for the reason that they are lithologically identical with the clays of Black Bluff, which is hardly more than a mile distant.

For the sake of greater completeness, we give below a few sections obtained in the southern part of Dallas County where the Ripley beds are exposed. These localities have acquired a practical interest from the circumstance that they include a bed of phosphatic greensand which has been used with profit upon the soil as a fertilizer. In addition to this greensand bed, there is also a sandy, phosphatic limestone which may some day be utilized, since it holds a very considerable percentage of phosphoric acid.

Snow Hill to Minter.—The town of Snow Hill occupies the summit of a long ridge, at the southern end of which the Nautilus and the Turritella rocks of the lowermost Tertiary form the surface, while at the northern end of the ridge the underlying yellow sands are the surface materials. Descending this ridge towards the north, one passes over yellowish gray, micaceous sands, alternating with hard, sandy ledges which flake off under the action of the weather. These strata are the same as those exposed on the hillside near the old Canton Landing and on the hill north of Prairie Bluff. Near the residence of Mr. W. S. Purifoy, a mile or so from Snow Hill, we see some fifty or sixty feet of these sands and shales overlying a bed of phosphatic greensand three feet or more in thickness. The section here exposed is the following:

(*k*) *Section near W. S. Purifoy's, near Snow Hill.*

1. Yellowish, micaceous sands, in beds four or five feet thick, separated by ledges of sandier material, which flakes off in weathering....................50 to 60 feet.
2. Phosphatic greensand, holding concretions of white carbonate of lime and a good deal of soft, white lime..4 feet.
   This greensand contains from 1.5 to 2 per cent of phosphoric acid. It lies very favorably at the foot of the hill, and at the level of the cultivated fields, and can be dug and spread upon the land with very little trouble or expense.
3. Hard, reddish or yellowish, phosphatic limestone, forming very irregular, concretionary masses..1 foot.
4. Yellowish, calcareous clays containing great numbers of large *Exogyra costata*, *Gryphæa mutabilis*, &c..20 feet.
5. Impure, argillaceous limestone, containing numbers of the shells above named, 10 to 15 feet.

This greensand has been tested practically by Mr. Purifoy, and with the most flattering results.

On Col. N. H. R. Dawson's place, adjoining Mr. Purifoy's on the north, the same beds are to be seen, together with some still lower. Below the greensand bed there are some sixty to seventy feet of calcareous, sandy beds with hard ledges, and near the base of the series an impure limestone weathering into calcareous clays, in which are embedded great numbers of *Exogyra costata*, *Gryphæa mutabilis*, and phosphatized shell casts, prominent among which are *Nautilus Dekayi*, and *Scaphites Conradi*. This shell deposit lies about six feet above a bed of hard, silicious phosphatic limestone or calcareous sandstone, which is the lowest of the strata here exposed.

Carlowville.—At Carlowville there is substantially the same section.

(l) Section at Carlowville, Dallas County.

1. A bed of phosphatic greensand holding much lime, in small concretions and in soft lumps easily crushed between the fingers.................... 4 feet or more.
2. A clayey, glauconitic limestone, which has been quarried for the purpose of building culverts on the railroad.. 3 feet.
3. Yellowish, calcareous, sandy shales with hard sandy ledges. The color of this material, where wet and not exposed to the weather, is dark blue like that at Bridgeport.. 60 feet.
   In the lower part of this there is an impure, argillaceous limestone which holds a great number of the two shells above named, together with casts (phosphatized) of others.
4. Hard, coarse grained, silicious limestone or calcareous sandstone .... 2 feet.

Richmond.—A few miles southwest of Richmond, on the land of Dr. J. P. Keyser, we get a more complete section embracing beds which overlie the preceding, viz:

(m) Section 3 miles southwest of Richmond, Dallas County.

1. Sandy shales, hardening into a shaly sandstone, forming a conspicuous ledge along the hillsides. This is underlaid by about 20 feet of calcareous sandy clays, similar to those near old Canton Landing.. 20 feet.
2. Calcareous, sandy ledge somewhat like the preceding, but perhaps more calcareous. This also overlies a series of calcareous shales, 35 feet or more............ 40 feet.
3. Bed of phosphatic greensand, with lumps of soft white limestone and concretions of lime .... 4 feet.
4. Impure, clayey, glauconitic limestone, making a shelf or ledge around the hillsides.. 3 to 5 feet.
5. Calcareous shales interstratified with beds of sandier material which form projecting ledges. These beds correspond in appearance to those forming the hill back of old Canton Landing, and where less exposed to the weather they still retain the dark blue color which is characteristic of them at Bridgeport. They hold the usual fossils in their lower strata, and in weathering give rise to the formation of a calcareous, clayey soil .... 60 to 70 feet.
6. Hard, silicious limestone, coarse grained and phosphatic, appearing near the water level at base of the hills.. 3 feet.

We have not yet given these localities the close examination which would enable us to say with certainty what their equivalents are; yet, from the position of the fossiliferous, impure limestone containing *Exogyra costata*, *Gryphæa mutabilis*, and the phosphatic shell casts above mamed, it seems quite probable that this greensand lies some 50 feet or nore above the fossiliferous beds of old Canton Landing and of Prairie Bluff. I should also add that, below the phosphatic, silicious rock at the base of the preceding sections, we have seen at other localities a yellow sand which is traversed by bands of silicious sandstone precisely as is the case at Prairie Bluff, so that we have very little doubt of the equivalence, although it is not certainly made out.[1]

These Upper Cretaceous rocks belonging to the Ripley formation have recently acquired a new interest from the circumstance that they are throughout the State very generally impregnated with phosphoric acid, often to such a degree as to render them available as materials for the manufacture of fertilizers. Thus the rock at Moscow and westward to Coatopa and Livingston and thence traced to Shuqualak, Miss., by Mr. Johnson, has been found to be phosphatic, and the same is true of the hard ledges of limestone rock occurring in the Canton bend, and thence eastward to Minter, and on to Fort Deposit, and thence to Chunnenugga Ridge and Union Springs. The occurrence and the characters of these phosphatic rocks will be more fully described at another place.

§ 2. THE ROTTEN LIMESTONE.

The next subdivision of the Cretaceous group, viz, the Rotten Limestone, extends for many miles along both the rivers, and, assuming a uniform dip of 25 to 30 feet to the mile, its thickness cannot be much less than 930 to 1,200 feet. The rock is of comparatively uniform composition, being a gray to bluish colored, argillaceous limestone, traversed at intervals by beds of purer limestone which is at the same time usually a little harder in texture. In some places the material is a dark bluish clay marl, in appearance not altogether unlike some of the blue or black clays at the base of the Tertiary group. The fossils of the Rotten Limestone are principally Exogyra, Gryphæa, and Ostrea, but in the upper and lower parts other forms become more abundant, forming transitions to the overlying and underlying subdivisions.

The best general view of the strata of the Rotten Limestone is afforded by the record of a boring for an artesian well at Livingston, Sumter County. The town is situated on the line of junction of the Rotten Limestone and Ripley formations, and the boring, therefore, passes through the whole of the former into the underlying Eutaw greensands. The boring was made from December, 1854, to March, 1857, and the record was carefully kept by Dr. R. D. Webb. The thickness of Rotten Limestone proper penetrated by this boring is 930 feet, the underlying sands and greensands belonging probably, for the most part, to the next division. The uppermost 20 feet are certainly in part drift and probably in part Ripley formation, though there are no fossils to decide the matter definitely.

[1]A bed of phosphatic greensand was discovered in 1886 by Mr. Langdon and myself at Prairie Bluff just overlying the limestone strata. Whether this is the same as the bed above described or a different one, we are not yet prepared to say.—E. A. S.

Section of the Rotten Limestone at Livingston, Sumter County. (*See Plate XXI, Column 4, p.* 183.)

	Materials.	Depth in feet.
1	Sandy loam, 1 foot	1
2	Coarse, dry sand, stratified, 12 feet	13
3	White quicksand (had to be curbed), 7 feet	20
4	Soft, rotten, blue limestone, thickly set with shells and containing iron	
5	pyrites, 180 feet	200
	White limestone, harder than the preceding, with very few if any shells or pyrites, 50 feet	250
6	Hard, blue limestone, so hard that the auger cuts it with difficulty, clear of shells and pyrites, 7 feet	257
7	Bluish white limestone, not so hard as the preceding, clear of shells and pyrites, 68 feet	325
8	Very hard, white limestone, 55 feet	380
	At 330 feet, passed through a stratum of oyster shells from which a specimen very much resembling an egg was brought up.	
9	Light blue limestone, not so hard as No. 8, but harder than No. 4, 47 feet	427
10	Bluish brown rock, filled with small shells. In this there was more sand than in the blue or white varieties of rock, 58 feet	485
11	Hard, white rock, 105 feet	590
12	Soft, reddish brown rock, 2 feet	592
13	Soft rock of deep blue color, 20 feet	612
14	Brownish blue rock, moderately soft, 78 feet	690
15	Hard, gritty, bluish colored rock, so hard that it had to be drilled, 6 or 8 inches	690
16	Dark bluish colored rock, easily cut by auger, 10 feet	700
17	Soft, whitish limestone, with occasional slight change in hardness and color, 250 feet	950
18	Hard sandstone, 6 feet	956
19	Sand, in which, at 964 feet, a small stream of water was reached, which ran feebly from the top of the well, 10 feet	966
20	Sand rock, 1 foot	967
21	Coarse greensand, in which a larger stream of water was reached at 1,005 feet depth, 38 feet	1,005
22	Sandstone, 2 feet	1,007
23	Greensand, 25 feet	1,032
24	Sandstone, 2 feet	1,034
25	Coarse greensand, 18 feet	1,052
26	Flint rock (crystallized), 1 foot	1,053
27	Very fine greensand, 9 feet	1,062
	In this greensand the well was stopped at a depth of 1,062 feet.	

In the following notes are given the characters of the Rotten Limestone as shown in a few prominent bluffs along the rivers, without any attempt to fix absolutely their position in the vertical scale of the boring.

The great degree of uniformity in the lithological characters and fossil contents of the different parts of the Rotten Limestone makes it impossible as yet to give the precise place in the vertical section of its exposures described below, with the exception of those which include the phosphatic greensands immediately below the limestone proper. We have, therefore, not attempted to represent the main body of the limestone except in the single plate illustrating the boring at Livingston; but in Plate XX we have given several figures illustrating the contact of the Rotten Limestone with the underlying, sandy beds.

EXPOSURES OF ROTTEN LIMESTONE.

About eight or nine miles above Moscow landing there is at Barton's Bluff an exposure of about sixty feet, consisting of dark bluish, clayey limestone, or perhaps better described a blue marl, with several harder ledges projecting from the face of the bluff. These ledges hold a good many fossils, the principal forms being *Ostrea falcata* in the upper ledges and large Gryphæa and Exogyra in the lower ones. These dark, clayey, limestone bluffs continue up the river to within nine miles of Demopolis. They are probably represented by No. 4 of the boring.

On the Alabama a similar material makes the bluff at Lexington Landing, and it holds also a large number of shells, especially those of Exogyra and other oysters.

At Demopolis the bluff is made of a very compact, light blue or gray limestone, which does not seem to be very highly fossiliferous. A similar limestone makes the bluffs for several miles down the river, nearly to Barton's Bluff, where, as already stated, it is more argillaceous and darker in color.

On the Alabama the counterpart of the Demopolis Bluff may be seen at Elm Bluff and at White Bluff.

The same rocks may also be seen on the Upper Tombigbee River (above the mouth of the Tuscaloosa) at Jones's Bluff, where the railroad bridge crosses the river.

Underlying the Demopolis limestone there is a stratum of undetermined thickness of a tolerably pure limestone of light yellow color, filled with concretionary lumps, cylinders, &c., of clay. When this clay washes out it leaves the limestone perforated in every direction, which circumstance is referred to in the name "bored rock." Below Arcola this bored rock is quite thick, and has bedding planes two or three feet apart, which cause the rock to break up into large cubical blocks.

At Arcola and at Hatch's Bluff, on the Tuscaloosa, the bored rock is near the top of the bluff, and underlying it is softer and crumbling Rotten Limestone of the usual character. The bored rock has sometimes been burned for lime, and its outcrop may be followed westward as far at least as Sherman, in Sumter County. It forms a rocky ridge wherever it comes to the surface.

The limestone underlying the bored rock for many feet is tolerably uniform in composition and resembles that of the Demopolis Bluff, except that it is, if anything, rather more argillaceous and less compact, being rather a white, calcareous clay than a limestone. There is nothing of interest to record at any of the bluffs of the river from Hatch's Bluff up to Wolf's Bluff, just above Cowan's Landing.

Here come in the strata, still better exposed higher up at Erie and at Choctaw Bluff, which form the transition between the Rotten Limestone and the sands of the Eutaw formation, and which probably represent the Tombigbee Sand group of Dr. E. W. Hilgard, if this group has its counterpart on the Tuscaloosa River.

Characteristic fossils of this horizon appear to be certain reptilian bones, Mosasaurus, the curious Hippurites, teeth of sharks, and large palatal teeth (*Ptychodus Mortoni* and others).

The lowermost strata of the Rotten Limestone (calcareous clays) also contain many of these fossils, and in addition to those mentioned, shells of Inoceramus in great numbers and of great size. These shells are of fibrous texture, the thickness of the shell (half an inch or less) forming the length of the fibres. In consequence of this structure the shells are very fragile and it is impossible to take them out unbroken except by removing a block of the matrix rock with them.

In no localities have I seen them in greater numbers and of larger size than in the long bluff at Fairfield, on the Tombigbee River, in the southern part of Pickens County, and in the fields back of House Bluff, on the Alabama River, in Autauga County. In the former place they are perfectly preserved, and many of them are more than a foot in diameter.

Near House Bluff they are seen in the old fields, associated with Leiodon bones, sharks' teeth, and phosphatic greensands. In the weathering of rock they break into fragments which, though slightly separated, retain their relative position and preserve the outline of the shell. In many cases these fragments cover a space three feet in diameter, indicating the size of the shell as at least two feet in diameter.

These would probably form the first of the transition beds above mentioned.

On the Alabama River these beds make their appearance above the latitude of Selma at Cunningham's and House Bluffs. Inasmuch as their paleontologic relations have not yet been determined and as they are more closely related in lithologic character to the Eutaw, we have thought it best to combine them with the latter formation in our description. The first five sections in the next division exhibit the Rotten Limestone in connection with the next underlying beds.

§ 3. THE EUTAW FORMATION.

As noted above, the sandy, fossiliferous strata lying beneath the argillaceous and calcareous rocks whose lithologic character is so well defined by the name of Rotten Limestone are referred by us to the Eutaw formation. In striking contrast with the Rotten Limestone, this series of deposits consists of sands and clays with little or no calcareous matter except in the uppermost 25 or 30 feet spoken of above as forming a transition between the Rotten Limestone proper and the sands of the undoubted Eutaw.

This upper member of the Eutaw formation consists at the summit of a bed 5 feet in thickness of indurated, calcareous sands, with numerous fossils and irregularly shaped nodules of nearly pure phosphate of lime, together with many highly phosphatized shell casts, and in addition the sand itself is very generally phosphatic. Below this bed there are 15 feet of sand with comparatively few fossils, except in a thin layer of compacted shells at the base and in two or three similar shell layers dividing the sand at different horizons. These shell beds are also usually phosphatic. Beneath the lowest comes a bed of greensand 6 to 8 feet in thickness, which is distinguished by its high percentage (5 per cent. and above) of phosphoric acid. These phosphatic and calcareous beds have been less closely examined on the Alabama River than on the Tombigbee, where they appear to be somewhat thicker.

The bulk of the lower and principal member of the Eutaw formation consists of cross bedded sands, with subordinate beds of pebbles and of thinly laminated clays with sandy partings in many alternations. The exact sequence of these beds is known only for about 80 or 90 feet below the phosphatic strata above mentioned. (See profile at the House Bluff, Alabama River, Pl. XX, Fig. 5, p. 175.)

The most striking peculiarities of the various beds of the lower member of the Eutaw formation are found in the abrupt changes which they undergo in both the vertical and horizontal directions. The dark gray, laminated clays with sandy partings seen at Finch's Ferry, Tuscaloosa River, may also be seen farther up the river at Semple's Bluff and at Brown's Bluff, and with nearly the same characters in all three localities. With this exception, however, I know of none of the Eutaw beds which preserve their characters with anything like uniformity for more than a few rods. Laminated clays pass into cross bedded sands or rather are replaced by them; cross bedded sands thin out abruptly, as if forming lenticular masses; the pebble beds thicken up and thin down rapidly within a few yards' distance; and indeed it is impossible to follow any of the beds with certainty from one end of a long bluff to the other, and it would be well nigh impossible to get two vertical sections of a bluff, 100 yards apart, which would exhibit the same sequence of materials. Two examples will illustrate my meaning. At Stave Bluff, Tuscaloosa River, half a mile long, we see at the upper end and near the center of the bluff a preponderance of laminated clays with thin intervening sheets of cross bedded sands, but at the lower end of the bluff the clays disappear or cease, not, however, by dipping below the water level, but abruptly, and they are replaced by thick beds of yellow sand which neither overlie nor underlie the clays, but are substituted for them on the same horizon. Again, at Merriwether's Landing, farther up the river, where the bluff is perhaps half a mile long, at the landing (upper end of the bluff) we find the bluff made up of laminated clays with sand partings, the sand partings becoming thicker and thicker as we descend, and assuming within 10 feet of the water the character of cross bedded sands with thin clay sheets following some of the lines of false bedding. One hundred yards or less below the landing the whole bluff appears to be cross bedded sands with clay seams, including, about twenty feet above the water, a 10 foot bed of sand. These change again, not because of the dipping of the strata below the river level, but because of the replacement at the same horizon of one set of beds by another.

The great mass of the Eutaw formation seems to have been deposited in shallow water by ever varying currents.

The absence of all fossils except an occasional lignitized tree trunk and the lack of any persistent or easily identified beds of any kind make it impossible for us here to sum up the thickness as we have done in the Tertiary group, and we are therefore compelled to rely either upon width of outcrop across the country of the beds of this formation or upon the borings for artesian wells. The thickness of the beds of this formation, estimated from their outcrop along the banks of the Tuscaloosa River from Finch's Ferry to Big Log Shoals, on an assumed uniform dip of 40 feet to the mile, is about 200 feet; but this estimate is probably too small. Between Big Log Shoals and White's Bluff no Cretaceous rocks are exposed on the river, but they may be seen upon the neighboring hills, and recent observations of Mr. Langdon and myself indicate that this stretch of the river is almost entirely underlaid by the beds of the Eutaw formation; and if this is so their total thickness can hardly be less than 300 feet. This estimate is confirmed by the width of the outcrop of the Eutaw beds upon the hills on both sides of the Tuscaloosa River. On the eastern side, in Hale County, they are found from three miles south of Havana down to Greensborough, and on the western side, in Green County, from just south of Knoxville down to Eutaw, or in each case about 10 miles in a direct line across the strike. This with a uniform dip of 30 feet to the mile would correspond to a thickness of 300 feet, and with a dip of 40 feet per mile to 400 feet; 300 feet may therefore be given as the minimum thickness of these beds along the Tuscaloosa. A boring now in progress at Eutaw reached the purple clays of the Tuscaloosa formation at a depth of 400 feet; which indicates a thickness for the formation nearly the same as that estimated from the width of outcrop and dip. The corresponding portion of the course of the Alabama River—i. e., between Selma and Montgomery—is such that the lowermost members of this formation are not there exposed.

SECTIONS OF THE EUTAW FORMATION.

The following sections illustrate fairly well the lithologic and other peculiarities of the Eutaw formation, including the transitional beds, which may hereafter, upon paleontologic grounds, be classed with the Rotten Limestone.

(a) Section of the bluff at Erie, Tuscaloosa River. (Plate XX, Fig. 1, p. 175.)

1. Rotten Limestone of usual character ....30 feet.
2. Indurated ledge of calcareous sand, containing grains of glauconite, strongly phosphatic and in part filled with oyster shells ....5 to 8 feet.
3. Yellowish sands containing shells in the upper part, and thus forming a continuation of the preceding ....8 feet.
4. Projecting hard ledge filled with small bivalve shells, chiefly oysters, 8 to 12 inches.
5. Yellowish sands, with some glauconite, becoming more and more glauconitic as we descend ....5 to 6 feet.

   The lower part of this stratum, say one or two feet, is indurated, shells become more abundant, and there is thus a gradual transition into the next underlying bed. In these sands, which are hollowed out from beneath the preceding ledge, there are embedded some curious stalagmitic formations, of indurated calcareous sand, which stand up like small pillars. These are strongly phosphatic, and have much the appearance and composition of the ledge No. 4.
6. Indurated ledge of sand, greensand, and shells, mostly oysters, like that at Choctaw Bluff ....1 foot.
7. Greensand, cross bedded ....3 to 4 feet.
8. Laminated, blue clay, in several distinct layers, which project from the vertical faces formed by the greensand above and below it ....2 feet.
9. Greensand like No. 7, but with more glauconite to water's edge; contains much phosphoric acid...1 foot.

Just above Erie there is a great southwestward bend in the river, by reason of which only the Rotten Limestone appears in the river banks, the greensands being all below the water level. This condition of things continues up to McAlpine's Ferry, where we have the following:

(b) Section near McAlpine's Ferry, Tuscaloosa River. (Plate XX, Fig. 2, p. 175.)

1. Rotten Limestone of variable thickness, with a covering of drift above it.
2. Calcareous sands, indurated and glauconitic, partly filled with shells, mostly oysters ....6 to 8 feet.
3. Sands..8 to 10 feet.
4. Greensand to water's edge ....6 feet or more.

From Eastport, just above McAlpine's Ferry, up to Melton's Bluff the course of the river is nearly along the strike of the strata, and we have practically the same beds as those above described at Erie along this stretch of the river. The undulations which are usually observed along the outcropping edges of our Tertiary and Cretaceous strata may be seen here also.

(c) Section at Melton's Bluff and Eastport, Tuscaloosa River.

1. Cross bedded sands, grading off below into greensand ....10 feet.
2. Greensand, forming a bench or ledge 6 to 8 feet broad and 3 feet thick down to the water's edge.

Between Melton's Bluff and Choctaw Bluff another great southwestward bend in the river causes the greensands to disappear below the water level, to reappear near the last named bluff, where we get the following very interesting section, which, however, embraces practically the same beds with the Erie bluff, the two places being situated from each other in the direction of the strike of the strata.

(*d*) *Section at Choctaw Bluff, Greene County, Tuscaloosa River.* (*Plate XX, Fig.* 3, *p.* 175.)

1. Rotten Limestone of the usual appearance, with a cover of drift or second bottom deposits. The rock contains some fossils, Inocerami, and bones of reptiles, 20 feet or more.
2. Indurated, calcareous sands, with some glauconite, filled with shells, mostly *Exogyra*, forming a projecting ledge, which is a very prominent and persistent mark along the face of the bluff[1] .... 6 to 7 feet.
3. Yellowish, cross bedded sands, shading off above into the fossiliferous ledge. These sands become more and more glauconitic and devoid of fossils below ..... 15 feet.
4. Indurated ledge of glauconitic sands and small oysters, slightly effervescent, phosphatic .... 1 foot.
5. Highly glauconitic sands, strongly phosphatic. These sands show above the water at the upper end of the bluff 6 to 8 feet, but sink below the water at the lower end, making a dip of about 20 feet to the mile along this stretch of the river.

This section shows well the point of contact of the Rotten Limestone with the glauconitic beds below it. The beds immediately under the Rotten Limestone are coarse, calcareous sands, somewhat indurated and filled with the shells of Exogyra, No. 2 above. Both the Rotten Limestone and the ledge are filled with nodular masses of iron pyrites. One mile below this, at Stevens's Bluff, the sands are all below the water, and only the Rotten Limestone above it; the same is true of the banks at Hamlet's Shoals. These beds, as above intimated, have acquired a considerable interest from the fact that most of them are strongly impregnated with phosphoric acid. This seems to be particularly the case with the glauconitic sands, especially when they are indurated; and in many cases the induration seems to be due to the formation of phosphates. Wherever the beds immediately underlying the Rotten Limestone have been examined, from the Mississippi line eastward to Wetumpka, and even farther toward the Georgia line, they have been distinguished by containing very notable quantities of phosphate of lime, either impregnating the greensands in a general way or concentrated into irregularly shaped nodules of nearly pure phosphate of lime. These, should they ever be found in sufficient quantity, will be of great value as an article of export. The phosphatic greensands, without the least doubt, can be very profitably used as fertilizers where they are convenient to transportation. This subject, however, will be more specially treated in the report of the Geological Survey of Alabama.

At Finch's Ferry, near Eutaw, on the Tuscaloosa River, there is a bluff which varies from 50 to 75 feet in height, in which strata underlying the phosphatic sands of Choctaw Bluff are seen. The upper 25 to 40 feet of this bluff (according to locality) consist of yellowish, cross bedded sands, in which a few indistinct fossils have been found, and below this some 25 feet of alternating blue clays and cross bedded sands;

[1] This bed has been called "Concrete Sand" by Prof. A. Winchell, and the next below it, "Loose Sand" (Proceedings Am. Assoc. Adv. Sci., Vol. X, Part II, p. 92, 1856). He, however, limits the former name to the first 2 or 3 feet below the Rotten Limestone.

then, forming base of the bluff, about 20 feet of laminated, blue clays, with partings of sand. No fossils have yet been observed in these lower beds.

(*e*) *Section at Finch's Ferry, Tuscaloosa River.* (*Plate XX, Fig.* 4, *p.* 175.)

1. Yellowish, cross bedded sands, with indurated bands at intervals. This sand contains a few casts of shells, mostly oysters, and pieces of silicified wood..25 to 40 feet.
2. Laminated, blue clays, with partings of sand..........................10 feet.
3. Alternations of cross bedded sands and blue, laminated clays...............5 feet.
4. Bluish, glauconitic sands ....10 feet.
5. Laminated, blue clays, the laminæ separated by thin sand partings.......20 feet.

The exact position of this section with reference to that at Choctaw Bluff is not certainly made out; but it is quite possible that some of the lowermost of the Choctaw Bluff beds may appear in the highest parts of the bluff at Finch's Ferry. At all events the two sections are very nearly conterminous.

On the Alabama River the same beds are seen at the Batte Smith Bluff, Cunningham's Bluff, and the House Bluff.

At the last-named locality we have perhaps the best section of the transition beds between the Rotten Limestone and the Eutaw formations to be seen in the State.

This bluff, gapped by ravines, forms the northern bank of the river for a mile or more at the top of one of those long bends made by the Alabama in this part of the State. Near the lower or western end of the bluff, where these gaps are close together, the sharp crested, interjacent ridges come out to the face of the bluff in cross section like the gable ends of a house, whence the name of the bluff.

The uppermost (i. e., most eastern) of these bluffs has about thirty feet of Rotten Limestone on top, and the washings from this have whitened all the underlying red and yellow sands, so that if not closely examined the white bluff would easily be mistaken for limestone throughout. The next bluff below separated from this by a narrow ravine only, and of nearly the same height, consists of yellow, cross bedded sands to the very top. The absence of the Rotten Limestone on top of this second bluff and its presence on top of the next succeeding or third bluff are due to undulations in the strata. The contrast between the first two bluffs is very striking. The uppermost bluff is probably the highest of the set and is about one hundred and fifty feet high, and the strata exposed in it are the following:

(*f*) *Section of the House Bluff.* (*Plate XX, Fig.* 5, *p.* 175.)

1. Rotten Limestone...20 to 30 feet.
2. Greensand, with phosphatic nodules.....................................4 feet.
3. Conglomerate of shells embedded in loose sand..........................1 foot.
4. Light colored sands, with irregular deposits of shells and a six inch layer of shells at bottom...5 feet.
5. Sands 8 feet, with a layer of shells at bottom, 1 foot, in all..................9 feet.[1]

[1] Nos. 2 to 5, inclusive, constitute the "Concrete Sand" of Dr. Winchell.

6. Alternating beds of horizontally laminated and cross bedded sands, yellow (glauconitic); the separate beds from 1 to 2 feet thick. These beds are marked with numerous streaks deeply colored with iron .... 40 to 50 feet.
7. Laminated clays (soapstone), devoid of fossils .... 10 feet.
8. Blue, micaceous sands, no fossils .... 15 feet.
9. Light colored sands, with large, bowlder-like concretions of concentric layers .... 20 feet.
10. Alternations of the laminated clays and blue sands above described down to the water level.

The great irregularity in the stratification of the sands of this formation is well exhibited in the House Bluff, where hardly any two sections will show the same sequence of beds. The following section of this bluff was taken by me in the summer of 1886, and shows the stratification of the first quarter of a mile of the bluff rather than that of a single locality:

(f^1) *Section of the upper part of House Bluff.*

1. Rotten Limestone, including near the base a bed of phosphatic greensand four and a half feet in thickness .... 30 feet.
2. Ledge of oyster shells embedded in sands, forming a hard ledge .... 8 inches.
3. Whitish sands .... 8 to 10 feet.
4. Ledge of shells like No. 2 .... 8 to 11 inches.
5. Yellowish, cross bedded sands, indurating into rounded, bowlder-like masses of concentric structure. On the weathering and caving of the bluff, these bowlders break off and roll down to the water's edge and cover all the slope below them. The two hard ledges of shell conglomerate also break off in a similar way, and their fragments also cover the slope below .... 50 to 60 feet.
6. Yellowish, cross bedded sands like the preceding, except that they are traversed by clay bands and partings of very irregular thickness and extent .... 10 feet.
7. Compact sands, making a smooth, perpendicular face .... 15 feet.
8. Cross bedded sands, the lower part containing gray clay partings, and in the lowermost 5 feet merging into bluish gray, laminated clays .... 15 feet.
9. Blue sands to the water's edge .... 5 feet.

The resemblance between this section and those of Choctaw Bluff and Finch's Ferry, Tuscaloosa River, is sufficiently strong to justify us in correlating them in a general way, though we cannot, of course, expect to find absolute identity in the individual beds.

The two ledges of shell conglomerate appear in the hills in many places westward of this bluff. Between the two Mulberry creeks, one and a half miles west of Statesville, they are nearly at the general level of the high table lands; and everywhere about seven or eight feet above the upper of these ledges, appears the bed of phosphatic greensand, so well known in the vicinity of Hamburg, in Perry County. These beds rise toward the north and appear in several places in Autauga County, high up on the hills. In the vicinity of the old Slaton place and the old Jim Brown place, the shell conglomerate and the greensands are exposed over a large territory.

All the bluffs of the Alabama River, from House Bluff up to Montgomery, show more or less of the House Bluff beds, according to the windings of the river. At Washington Ferry the banks are made of the laminated gray clays with interbedded sands, which are seen near the base of House Bluff. About two hundred yards above the Washington Ferry there is a high red bluff showing the following:

(f^2) Section of bluff near Washington Ferry, Autauga County.

1. Drift and red loam ....10 to 15 feet
2. Cross bedded, yellow sands, stained deep red by the washings from No. 1..50 feet.
3. Laminated clays and sands ....50 feet.

No. 2 above corresponds with No. 5 of my House Bluff section, while No. 3 corresponds to the rest of the House Bluff.

The river bluff, just below the steamboat landing at Montgomery, shows the following:

(f^3) Section at Montgomery.

1. Drift (very closely resembling what we have called second bottom deposits), 15 to 20 feet.
2. Laminated, gray sands, with gray clay partings..............................3 feet.
3. Gray clayey sands, with white and gray clay partings......................4 feet.
4. Rather compact, yellow sands with small, lens-shaped, spherical, and other irregularly shaped masses of pure, gray clay scattered through the mass of sands. These form the greater part of the perpendicular bluff to the river below the drift deposits, and extend to the water's edge ....25 to 30 feet.

Where the Rotten Limestone is seen at the summit of the bluff, as at Choctaw Bluff and at House Bluff, the geological horizon of the underlying beds of the section is at once determined. The uncertainty is felt only in regard to the exact relative position of the Finch's Ferry beds and those where the Rotten Limestone is absent.

Between Finch's Ferry and Big Log Shoals, a distance of four and a quarter miles or a little more, across the strike, which corresponds to a thickness of about one hundred and fifty feet of strata, the banks of the river are composed of laminated, bluish clays and cross bedded, glauconitic sands, in many alternations. Interbedded with these, at two or three points, are thin beds of pebbles, from eight to twelve inches thick, and thin layers of lignitic matter, consisting of lignitized stems, twigs, and other fragments, embedded in bluish sands. In addition to these, lignitized trunks of trees are not infrequently seen at many of the exposures. Occasionally, also, a silicified trunk is to be found lying upon the bluff, but whether derived from the Cretaceous or from the overlying drift deposits is still a matter of doubt.

It has as yet been impossible to ascertain the actual sequence of these different beds for the whole distance mentioned above, but the following detailed sections will probably cover nearly their entire thickness.

Immediately below the laminated clays which form the base of the exposure at Finch's Ferry, come alternations of similar laminated clays, with cross bedded sands many feet in thickness, which are to be seen at Semple's Bluff, just above the railroad bridge, and at Collins's wood yard, where about ten feet of thickness are to be seen.

Childs's Ferry.—At Childs's Ferry similar strata are exposed, the bluff being some thirty feet high. The lower part of this exposure consists, without doubt, of the same beds as those at the top of the bluff at Merriwether's Landing, given below:

(g) Section at Merriwether's Landing, Tuscaloosa River.

1. Laminated clays and sands; the sands are bluish green in color when freshly exposed, but become yellowish on weathering........................10 to 15 feet.
2. Sands ....7 to 8 feet.
3. Laminated sands and clays again to the water's edge............20 feet or more.

Much of the blue clay in the lower part of this bluff breaks up on drying into small chips, which are covered with white efflorescence derived from the oxidation of iron pyrites, nodules of which are of common occurrence in the clay. Along the bluff are to be seen many trunks of trees, either lignitized or silicified.

The lowermost five or ten feet of the beds exposed at Merriwether's are seen again at the top of the bluff at Long Bend, where the following section is exposed:

(h) Section at the head of Long Bend, Tuscaloosa River.

1. Cross bedded sands forming top of bluff..............................5 to 10 feet.
2. Laminated, blue clays..2 to 3 feet.
3. Bed of quartz pebbles..2 to 3 feet.
4. Laminated, blue clays again, containing galls or concretions of pure, light colored clay...4 to 5 feet.
5. Coarse grained, yellowish sands, strongly cross bedded, running down to the water level...5 feet or more.

Hickman's.—At Hickman's, below Big Log Shoals, the bluff is made up of laminated clays alternating with cross bedded sands in the most irregular manner. The thickness of these beds was not estimated, but their relative position is as follows:

(i) Section at Hickman's, Tuscaloosa River.

1. Cross bedded sands of yellowish color on exposed surfaces, probably 10 feet or more in thickness.
2. Laminated, blue clays, more or less sandy and containing lignitized tree trunks, which are, in general, pyritous. The laminated, blue strata in the upper part of this division are much more clayey than those in the lower part, and mark the bluff with parallel and approximately horizontal stripings, probably 5 to 10 feet.
3. Cross bedded sands again down to the water's edge.

At the head of Big Log Shoals we have another section of ten or twelve feet, as follows:

(j) Section at the head of Big Log Shoals, Tuscaloosa River.

1. Compact, blue, micaceous sands..................................3 to 4 feet.
2. Laminated sands ....3 to 4 feet.
3. Lignitic stratum, consisting of lignitized twigs, stems, and other fragments, embedded in bluish sands..1 foot.
4. Alternating layers of blue clay and bluish, micaceous sands, the latter including a bed of pebbles 8 to 10 inches in thickness..........................4 to 5 feet.

This section represents the lowermost of the blue clays and cross bedded sands, which we have considered as belonging to the Eutaw formation of the Cretaceous group, leaving undetermined some seventy-five feet from this to White's Bluff. At the latter begins what we shall now call the Tuscaloosa formation.

III. OTHER MESOZOIC STRATA, PROBABLY CRETACEOUS.

§ 1. THE TUSCALOOSA FORMATION.

Underlying the strata last described, and forming all the country between White's Bluff and the city of Tuscaloosa, are beds whose age has not been certainly determined.

The most conspicuous rocks are purple and mottled clays interstratified with white, yellowish white, pink, and light purple, micaceous sands, and near the base of the formation dark gray, nearly black, thinly laminated clays, with sand partings. Typical sections of the mottled clays and white sands may be seen at Steele's Bluff and at White's Bluff on the Tuscaloosa River; and a beautiful section of the pink, micaceous sands is exposed in two large gullies below Havana, in Hale County, near the residence of Hon. A. M. Avery. The dark gray, laminated clays are well seen near and in the city of Tuscaloosa.

All the beds of this formation, being of loose clays and still less coherent sands, have suffered a great amount of denudation, and in consequence they form the banks of the river at only a few points.

(1) SUMMARY OF PREVIOUS OBSERVATIONS AND OPINIONS.

The peculiar formation above described appears to have been observed a third of a century ago by Prof. L. Harper, then State Geologist of Mississippi, and by Prof. Alexander Winchell.

In 1856 Professor Harper described three specimens of *Ceratites*, which he called *C. Americanus*,[1] found by him in 1853 in the bed of the Tuscaloosa (or Warrior) River near Erie, and pronounced by the elder Agassiz "closely allied to *Ceratites Syriacus* of L. v. Buch," from the Cretaceous rocks of the Caucasus. Professor Harper considered it "somewhat doubtful" whether this was a Cretaceous fossil, and suggested that it was washed out from the formation underlying the known Cretaceous beds of that section of Alabama. He adds: "What formation this is seems difficult to decide, it being devoid of fossils. It must, of course, be one of the older formations intermediate between the coal [Carboniferous] and the lime [Cretaceous], and I should not at all be astonished if a careful examination should give the result of its classification among the poikilitic rocks, to which this variegated clay bears great resemblance."[2] Subsequently, in his Report on the Geology of

[1] Proc. Acad. Nat. Sci. Phila., Vol. VIII, pp. 126–128.

[2] Ibid., p. 28.

Mississippi,[1] he speaks of the occurrence of a clay of greenish blue color with red streaks, penetrated by a boring for an artesian well at Columbus, Miss., and he looks upon the occurrence of this clay as an evidence that "there exists between the Cretaceous and the Carboniferous formations an intermediate one, perhaps the Permian;" and in the same connection he again mentions the occurrence of great beds of variegated clays below the greensand of the Cretaceous formation above the town of Eutaw, in Alabama, and repeats his suggestion that the three specimens of Ceratites were "most probably washed out of a formation underlying the Cretaceous formation." With respect to the age of the infra-cretaceous formation he adds: "The *Ceratites* being especially a fossil of the Triassic formation, it is possible that this formation underlies the Cretaceous."[2]

In 1856, also, Professor Winchell mentioned the beds of sand and clay which underlie the sands of Finch's Ferry, remarked upon the variegated and mottled colors of the clays and also of the red sandstone, and added that in Greene County many of the artesian wells which penetrate these beds furnish a constant supply of salt water (showing the occurrence of local deposits of salt), while the deeper borings brought up an abundance of quartzose pebbles; all of which he considers compatible with the supposition that these deposits are of Triassic age.[3] This supposition is still further strengthened by the occurrence of "remains of vegetables appearing like the stems and leaves of dicotyledonous plants, * * * some specimens of which appeared to me indistinctly allied to stems of *Equisetites*." Professor Winchell also remarks upon the great scarcity of any organic remains in all these beds, extending to the very suburbs of the city of Tuscaloosa, which, he says, "renders the determination of their age extremely doubtful;"[4] and he is evidently not fully convinced of the Triassic age of the beds, since in his table of principal strata,[5] he includes them in the Lower Cretaceous.

From these extracts it seems certain that both Harper and Winchell were aware of the existence of this formation as early as 1856, if not in 1853. No unmistakable reference to these strata has been found in Professor Tuomey's writings, though he must have known of the observations of the two gentlemen above named. It must be remembered, however, that at the time of his death Professor Tuomey had a large number of unpublished notes on the geology of Alabama, many of which have been lost. It is true that in 1850 Tuomey described certain "superficial beds of red loam," &c.,[6] and that as early as 1846 Lyell mentioned "great beds of gravel and sand" in the vicinity

[1] Prel. Rep. Geol. and Agric. Miss., p. 279, 1857.
[2] Ibid., p. 280.
[3] Proc. Am. Assoc. Adv. Sci., Vol. X, Part II, p. 92, 1856.
[4] Ibid., p. 93.
[5] Ibid., p. 84.
[6] First Bien. Rep. Geol. Ala., p. 164, 1850.

of Tuscaloosa;[1] but these great beds of gravel, sand, and loam which constitute so large a proportion of the surface material about Tuscaloosa are undoubtedly, as Professor Tuomey has said, of comparatively recent age, though possibly derived primarily from a Mesozoic formation. Certainly neither Lyell's nor Tuomey's description applies to the predominant beds of the Tuscaloosa formation, and it appears equally certain that, when their descriptions were written, neither of these authors had in view the laminated and mottled clays of the formation, which appear only here and there in comparatively insignificant exposures in a few of the gullies back of the city, the majority of these gullies exposing only post-Tertiary gravels and sands.

The age of the various Mesozoic deposits of Alabama was discussed at great length nearly thirty years ago by Hall, Meek, Conrad, Hayden, and others.

In 1855 Hall and Meek, referring to Tuomey's publications, classed the various Mesozoic strata of Alabama as Cretaceous.[2] Two years later Meek and Hayden, making use of the information published by Tuomey, Harper, and A. Winchell, together with additional matter privately communicated by the last named gentleman,[3] correlated the lower portion of the Alabama Mesozoic[4] with the lowest Cretaceous formation of New Jersey and Nebraska and the lower strata of Pyramid Mountain, New Mexico (regarded by Marcou as Jurassic and Triassic).[5] Among their conclusions are these:

> 7th. There is at the base of the Cretaceous system, at distantly separated localities in Nebraska, Kansas, Arkansas, Texas, New Mexico, Alabama, and New Jersey, if not indeed everywhere in North America where that system is well developed (at any rate east of the Rocky Mountains), a series of various colored clays and sandstones, and beds of sand, often of great thickness, in which organic remains, excepting leaves of apparently dicotyledonous plants, fossil wood, and obscure casts of shells, are very rarely found, but which everywhere preserves a uniformity of lithological and other characters, pointing unmistakably to a similarity of physical conditions during their deposition over immense areas.
>
> 8th. Although the weight of evidence thus far favors the conclusion that this lower series is of the age of the Lower Greensand, or Neocomian of the Old World, we yet want *positive* evidence that portions of it may not be older than any part of the Cretaceous system.[6]

[1] Quar. Jour. Geol. Soc., Vol. II, p. 280, 1846; Second Visit to North America, Vol. II, p. 79, 1855.

[2] Trans. Am. Acad., Vol. V, p. 380, 1855.

[3] Proc. Acad. Nat. Sci. Phila., Vol. IX, pp. 117-133, 1857.

[4] Described (Proc. Acad. Nat. Sci. Phila., Vol. IX, p. 126, 1857) as "beds of dark blue, soft shale or indurated clay, alternating with strata and seams of white and mottled clays, green and ferruginous sand, and dark, pyritiferous shale. No organic remains, but stems and leaves of apparently dicotyledonous plants and a few obscure casts of other fossils. *Ceratites Americana* of Harper, is, however, supposed to hold a position somewhere in this series."

[5] Pac. R. R. Rep., Vol. III, Résumé and Field Notes, p. 137, 1853-'54.

[6] Proc. Acad. Nat. Sci., Vol. IX, p. 133, 1857.

Later, in the same year, Hall[1] pointed out that Marcou's erroneous reference of the Pyramid Mountain beds to the Jurassic and Triassic was at least partly due to mistaken identification of certain fossils, and followed the former authors in definitively referring the several formations in question to the Cretaceous, of which the lower division is "represented by No. 1 of the Nebraska section, and including the various sandstones and shales or clays at the base of the formation in the Llano Estacado and other portions of New Mexico; and probably equivalent to the lower clay beds of New Jersey [and Alabama],[2] in which the only fossils yet known are of vegetable origin,"[3] while Conrad was of the opinion that the Cretaceous deposits of Alabama form a passage or intermediate stage between the Cretaceous strata of Texas" and those of New Jersey.[4] Subsequently Hilgard (who was unquestionably familiar with the suggestions of Harper and Winchell as to the pre-Cretaceous age of the clays and sands resting upon the Carboniferous strata in Alabama and Mississippi) united the beds immediately beneath the Tombigbee sands and the subjacent highly colored clays and sands, applied the name Eutaw group to the formation thus defined, and referred it to the Cretaceous.[5] In the following year Meek and Hayden re-expressed their convictions as to the age of the lowest Mesozoic beds of Alabama, correlated the beds subsequently described by J. S. Newberry[6] and B. F. Shumard[7] with the formation to which they had already referred these deposits, and applied to it the name Dakota group.[8] In 1869 Safford followed Hilgard in uniting the lowest Mesozoic beds of Western Tennessee with the immediately superjacent strata containing Cretaceous fossils; and to the formation thus defined he gave the name Coffee Sand.[9] The latest specific expression on the subject known is that of Meek, who, in 1876, with the entire information available before him up to the initiation of the investigations herein described, maintains his opinion that the beds of dark blue, soft shale or indurated clay &c. of Alabama, the plastic clays of New Jersey, and the yellow and brown sandstones and green shales of New Mexico, to which he added the Eutaw group of Mississippi, are Cretaceous and the equivalent of the Dakota formation of Dakota, Nebraska, and Colorado;[10] but Lesquereux has recently correlated the Dakota

[1] Am. Jour. Sci., 2d ser., Vol. XXIV, pp. 72–86, 1857; also Rep. U. S. and Mex. Bound. Surv., Vol. I, Pt. II, 1857.

[2] Am. Jour. Sci., 2d ser., Vol. XXIV, p. 75, 1857.

[3] Ibid., p. 83.

[4] Rep. U. S. and Mex. Bound. Surv., Vol. I, Pt. II, p. 141, 1857.

[5] Rep. Geol. and Agr. of Miss., p. 61, 1860.

[6] Rep. Expl. Exped. 1859 under Macomb, p. 52, 1876; Am. Jour. Sci., 2d ser., Vol. XXIX, p. 208, 1860.

[7] Trans. Acad. Sci. St. Louis, Vol. I, pp. 582–590, 1856–1860.

[8] Proc. Acad. Nat. Sci. Phila., Vol. XIII, pp. 419–421, 1861.

[9] Geol. of Tenn., p. 411, 1869.

[10] U. S. Geol. Surv. Terr., Vol. IX, pp. 38–42, 1876.

group of Meek and Hayden with the Cenomanian of Europe,[1] thereby increasing the probability that the formations subjacent to the Eutaw or other well defined portions of the Dakota group may belong to the Cretaceous.

Examination of their literature shows, however, that these geologists failed to discriminate the poorly fossiliferous beds denominated Eutaw in Mississippi and Alabama and Coffee Sand in Tennessee from the subjacent and apparently much older formations now in question; and, since their determination of the age of the entire series of strata rests on the evidence of the fossils from the admittedly Cretaceous Eutaw group, their opinion as to the age of the subjacent formations is of little value.

Although the poverty of the formation in organic remains precludes the possibility of determining its precise position in the geologic series, its relation to other Mesozoic formations of the eastern United States is suggested by its attitude, its lithologic character, and its stratigraphic position.

On comparing it with the Red Sandstone of New Jersey and Connecticut (generally regarded as Triassic, though W. M. Fontaine has recently pronounced certain bodies of it Rhætic < Lower Liassic[2]) marked differences are found to exist. Thus the deposits of the Tuscaloosa formation are seldom lithified, while those of the Red Sandstone are, in general, firm sandstones, conglomerates, and shales; the strata of the Tuscaloosa formation are little disturbed (having only a gentle inclination of thirty or forty feet per mile to the seaward), while the Red Sandstone is everywhere highly tilted, faulted, slickensided, and sometimes contorted; the former formation has never been affected by intrusives, while the latter is intersected by trap dikes and interbedded with trap sheets; vegetal matter in the formation exposed along the Tuscaloosa River is comparatively little altered, and often retains its woody texture, although it is usually converted into lignite, while the carbonaceous matter of the Red Sandstone on Deep and Dan Rivers and elsewhere has been converted into true coal. Both formations are alike unconformable to the subjacent and Paleozoic and Azoic formations; but while the former is sensibly conformable to known Cretaceous formations the latter is apparently separated from the adjacent (but nowhere contiguous) later Mesozoic deposits by one of the greatest unconformities of the American rock series; and finally, while only slight and uniform elevation appears to have occurred in the eastern part of the continent since the formation of the Alabama deposit, great changes in continental configuration have unquestionably taken place since the formation of the highly tilted Red Sandstone of New Jersey and the Connecticut Valley. Accordingly these formations could not

[1] Rep. U. S. Geol. Surv. Terr., Vol. VIII, pp. 92, 105, 1883.
[2] Mon. U. S. Geol. Surv., Vol. VI, pp. 96, 128, 1883.

legitimately be correlated without the strongest possible paleontologic evidence; and such evidence has not been found.

But on comparing the formation with the younger Mesozoic deposits of Eastern Virginia, Central Maryland, Northern Delaware, Southeastern Pennsylvania, and perhaps Central New Jersey and Southern New York—the Potomac formation of McGee—there is found to be so striking similarity in attitude, in composition, in degree of lithification, and in stratigraphic position that the description of the one in general terms will equally apply to the other; and this similarity will warrant provisional correlation of the formations.

The age of the Potomac formation has not, however, been satisfactorily determined, as the following history of opinion concerning it indicates:

It appears to have been first discriminated by R. C. Taylor[1] who, in 1835, spoke of it in one of its exposures as "The Secondary Horizontal Strata of Fredericksburg," and described half a dozen species of fossil plants from it, and, on the evidence of the plants, referred it to the "Oölitic group of Europe." Its probable equivalent was again separated from the fossiliferous Cretaceous deposits in New Jersey in 1840 by H. D. Rogers, who denominated it the "Potter's Clay formation," referred it to the "Upper Secondary series,"[2] (in contradistinction to the "Middle Secondary series," to which the Red Sandstone was relegated), and showed that it passes gradually upward into the greensand division of the Cretaceous. In the following year it was specifically designated the "Red Clay formation" in Delaware, and referred to the "Upper Secondary formation," on the ground of its resemblance to the "Secondary" formation of Europe;[3] and in the same year it was described in Virginia by W. B. Rogers, who denominated the formation the "Upper Secondary Sandstones and Conglomerates,"[4] in contradistinction to the "Middle Secondary Sandstone" &c. (comprised in the Rhætic of Fontaine). In 1842, he referred it to the Oölitic[5] and again in the same year (as a subsequent publication indicates) "to the upper part of the Jurassic series, corresponding probably to the Purbeck beds of British geologists."[6] The bases for these references appear to have been (1) the evidence of undescribed plant and animal remains, (2) the lithologic character of the deposits, and (3) the stratigraphic relations of the formation. In 1845, after examining this and associated formations in company with Conrad, Sir Charles Lyell[7] "arrived at the conclusion that the whole of the New Jersey series [of

[1] Trans. Geol. Soc. Pa., Vol. I, pp. 320–325, 1835.
[2] Geol. of N. J., Final Rep., pp. 177–179, 1840.
[3] Memoir Geol. Surv. Del., 1837–'38, pp. 14–16, 1841.
[4] Rep. Prog. Geol. Surv. Virg., p. 29, 1840.
[5] Reprint, Geol. of the Virginias, p. 542.
[6] Proc. Bos. Soc. Nat. His., Vol. XVIII, p. 104, 1875.
[7] Trav. in N. A., Vol. I, p. 63, 1845.

Cretaceous deposits] agrees in its chronological relations with the European White Chalk, or, to speak more precisely, with the formations ranging from the Gault to the Maestricht beds inclusive;" but his language in another publication suggests that his expression is designed to apply only to the fossiliferous formations overlying the plastic clays constituting the upper division of the Potomac formation.[1] Certainly, his conclusion rested in large part on his own observations of conformity and collections of shells from the fossiliferous formations. In 1867, as already mentioned, Meek and Hayden, after visiting the exposures and examining the collections of the State geologic survey and discussing the paleontologic, lithologic, and stratigraphic evidence then available, correlated the plastic clays forming the base of the newer Mesozoic of New Jersey—the "Potter's Clay" formation of H. D. Rogers—with the European Neocomian.[2] In 1860, Tyson recognized what appears to be the same formation in Maryland, denominated it "Formation No. 21,"[3] and, on the questionable evidence of a few imperfectly silicified casts of undetermined fossils, a new genus of Cycas, silicified and lignitized coniferous wood, a fragment of a rib of a whale, and "part of the teeth and bones of an herbiferous Saurian," referred it (including the "Iron Ore Clays") to the Cretaceous; but two years later, on the evidence of the cycad alone, concluded (with the expressed concurrence of L. Agássiz) that it ought to be placed "at least as low as the Oölitic period."[4] On assuming control of the geologic survey of New Jersey, Cook recognized and repeatedly described the formation constituting the base of the newer Mesozoic series. In 1865 he denominated it the "Fire and Potter's Clays" and definitively referred it to the Cretaceous,[5] though without explicit statement of the reasons for the reference. In the same year Leidy[6] adopted the taxonomy of Meek and Hayden, and described and referred to the Cretaceous a reptilian tooth (*Astrodon Johnstonii*) from the "Iron Ore Clays" of Maryland. In 1868, Cook substituted the name "Plastic Clays"[7] for the formation as developed in New Jersey, and correlated it with the Lower Greensand of Europe on paleontologic and stratigraphic grounds. During the same year, however, Conrad[8] referred the formation to the Triassic, on the evidence of two casts of lamellibranchs (called "Cretaceous species" in the title), and a few plant remains referred to the genus Cyclopteris, which he found within it; while Cope, who found within it in Western New Jersey "leaves of dicotyledonous trees, ctenoid fish scales,

[1] Quar. Jour. Geol. Soc., Vol. I, p. 60, 1845.
[2] Proc. Acad. Nat. Sci. Phila., Vol. IX, pp. 127-133, 1857.
[3] First Rep. Agr. Chem. Maryland, pp. 41-43, 1860.
[4] Sec. Rep. Agr. Chem. Maryland, p. 54, 1862.
[5] Ann. Rep. Geol. Surv. N. J., p. 24, 1864.
[6] Smithsonian Cont., Vol. XIV, Cret. Rep. U. S., pp. 2-4, 1865.
[7] Geol. of N. J., pp. 36, 241, 246-248, 1868.
[8] Am. Jour. Conc., Vol. IV, p. 279, 1868.

and numerous Unionidæ in a tolerably good state of preservation," correlated it with Meek and Hayden's "Earlier Cretaceous No. 1" (Dakota), although the six species of Unios and Anodontas contained within it have "some analogy with those of the Wealden, procured by Dr. Mantell in England."[1] In 1875 W. B. Rogers,[2] referring to Tyson's discovery of stumps of cycads in the formation, relegated it to the horizon of the Upper Jurassic rocks, and suggested that "we may find here a passage group analogous to the Wealden of British geology." In the next year, after an exhaustive review of its paleontologic and stratigraphic relations, Meek[3] referred the formation unquestioningly to the Cretaceous, and suggested that it represents a "part, if not the whole, of the Upper Greensand." In 1878 Cook retained the name "Plastic Clay" for the formation as developed in New Jersey, and, on the authority of Lesquereux and Gabb, who examined, respectively, the plant and animal remains found within it, again correlated it with the Lower Greensand of Europe.[4] Lesquereux remarks that the plant remains of the formation have, "so far as they are determinable, the characters of the flora of the Dakota group, or of the Lower Cretaceous of Nebraska and Kansas. This is Lower Cretaceous for this country, equivalent to a lower member of the Upper Cretaceous of Europe."[5] During the next year Fontaine described the formation as exhibited in the Fredericksburg and Petersburg belts, and, on the evidence of a moderately abundant flora, correlated the upper division of the strata of the former belt with the Wealden[6] and those of the lower part with the Upper Oölite,[7] and referred the whole of the Petersburg belt to the Wealden.[8] In 1880 (?) Dana[9] adopted the taxonomy of Meek and Hayden, and referred the Plastic Clay of Cook and the correlative deposits in Delaware, Maryland, and Virginia to the Cretaceous, to which he also ascribes the Alabama beds supposed to yield Harper's doubtful genus *Ceratites*.[10] In 1881 this formation was recognized in Pennsylvania by C. E. Hall[11] (though its existence there was long ago denied by H. D. Rogers),[12] who denominated it "Wealden Clay" and classed it as "a remnant of the lowest clay beds of the New Jersey Cretaceous (Wealden ?)." In the same year Britton[13] denominated

[1] Proc. Acad. Nat. Sci. Phila., Vol. XX, p. 157, 1868.
[2] Proc. Boston Soc. Nat. His., Vol. XVIII, p. 105, 1875.
[3] Rep. U. S. Geol. Surv. Terr., Vol. IX, p. xliv, 1876.
[4] Rep. Clay Deposits of N. J., pp. 25–30, 1878.
[5] Ibid., pp. 27, 28.
[6] Am. Jour. Sci., 3d ser., Vol. XVII, p. 156.
[7] Ibid., p. 157.
[8] Ibid., p. 233.
[9] Man. of Geol., Dana, 3d ed., pp. 454–458.
[10] Ibid., p. 468.
[11] Sec. Geol. Surv. Pa., Rep. Prog., C^6, p. 19.
[12] Geol. Pa., Vol. I, p. 59, 1858. "Tertiary and Cretaceous strata border the State upon the SE. in New Jersey, but they do not cross the Delaware River into Pennsylvania."
[13] Ann. N. Y. Acad. Sci., Vol. II, p. 170, 1882.

the formation as represented on Staten Island the Cretaceous formation and remarked that it is "a direct continuation of the 'Plastic Clay' division of the Cretaceous, so named by the New Jersey geologists, and lie[s] at the base of the formation in Eastern North America." Newberry[1] also, during the same year, expressed the conviction that these strata are Cretaceous. In 1883 Fontaine[2] discriminated the older Mesozoic and the younger Mesozoic of Virginia, and remarked that "the younger Mesozoic strata have very little in common with" the older, but expressed no more definite opinion as to their age. In the same year Uhler[3] described the formation as developed in Maryland in a popular address, discussed its flora and fauna, denominated it the Wealden, and referred it to the upper part of the Jurassic. A year later Chester[4] applied the New Jersey name of Plastic Clay to the formation in Delaware and referred it to the "Lower Cretaceous (Wealden ?)," but upon what basis is not evident. In the same year appeared W. B. Rogers's posthumous geologic map of Virginia and West Virginia,[5] in which the formation is classed as "Upper Jurassic passing upward into base of Cretaceous." In the same year also McGee,[6] after assembling and adjudicating the entire available evidence as to the age of the formation, provisionally mapped it as Cretaceous.[7] One of the latest published expressions, and perhaps the most authoritative, is that of R. P. Whitfield, who describes five species of lamellibranchiate shells from this formation in New Jersey. Whitfield considers that "Mr. Conrad may have been mistaken" in regard to the casts of *Astarte* from the ash colored clays of this formation, referred by him to the Triassic, and expressed the "feeling" that the formation more probably represents the Jurassic than the Cretaceous.[8] In the same volume Cook applies the eminently suitable name Raritan Clays[9] to the formation as developed in New Jersey, and, on stratigraphic grounds, adheres to his opinion that the formation is a part of the Cretaceous. Still more recently Fontaine[10] has re-examined the various exposures of the formation in Virginia and made extensive collections of plant remains from them. He finds that while the general facies of the flora is Neocomian there is a notable commingling of Jurassic and even earlier forms. Accordingly the precise equivalence of the formation with any of the European or western American divisions cannot be established.

[1] Trans. N. Y. Acad. Sci., Vol. I, p. 57, 1881–'82.
[2] Mon. U. S. Geol. Surv., Vol. VI, p. 2, 1883.
[3] Johns Hopkins Univ. Cir., Vol. II, p. 53, 1883.
[4] Proc. Acad. Nat. Sci. Phila., pp. 250–2, 1884.
[5] Reprint Geol. of the Virgs., map, 1883–'84.
[6] Fifth Ann. Rep. U. S. Geol. Surv., Pl. II, 1883–'84.
[7] Fifth Ann. Rep. U. S. Geol. Survey, Pl. II, 1885.
[8] Mon. U. S. Geol. Surv., Vol. IX, pp. 22, 23, 1885.
[9] Ibid., p. x.
[10] Sixth Ann. Rep. U. S. Geol. Surv., pp. 85 and 86, 1884–'85.

2. OBSERVATIONS FROM 1883 TO 1886 OF OCCURRENCES ON THE TUSCALOOSA.

The recent work upon the basal Mesozoics in Alabama may be summarized as follows: In the spring of 1883 Mr. L. C. Johnson, while engaged in the work of the U. S. Geological Survey, observed the purple and mottled clays, briefly described above, in Dallas County, and on Big and Little Mulberry Creeks in Autauga County, and obtained from well borers many notes of their occurrence, and conjectured that they belonged to a formation anterior to the Cretaceous. I had seen the same clays in 1871 on the road between Tuscaloosa and Eutaw, without reaching any decision as to their age. In August, 1883, upon the joint excursion of which this paper is the record, we had the satisfaction of observing every outcrop of these beds along the Tuscaloosa River below Tuscaloosa, and in the autumn of 1884, at the joint expense of Mr. T. H. Aldrich and the Geological Survey of Alabama, Mr. D. W. Langdon, jr., undertook an excursion through Bibb County along the Cahaba River, for the purpose of studying this formation there.

In the summer of 1885 the writer had the opportunity of examining many exposures of these clays and sands in the interior of Tuscaloosa, Hale, Bibb, and Autauga Counties.

In the early part of 1886 we found in the city of Tuscaloosa a fine exposure of dark gray, laminated clays, full of leaf impressions, which promise to furnish the means of determining definitively the age of the formation.

Some leaf impressions collected by Mr. Langdon and the writer in Bibb County were submitted to Professor Leo Lesquereux. One of these was considered by him to be referable to the genus *Podozamites*, with affinities to *P. lanceolatus* and *P. distans* of the Trias or Rhætic, and with still closer affinities to *P. pulchellus* Heer, from the Jurassic of Spitzbergen. Professor Lesquereux remarks: "I have found some species of the genus in the Cretaceous, but none with leaves of the same form as yours. The *P. pulchellus* has, like your leaf, distinct, coarse, somewhat distant primary nerves, separated by thin, punctate ones."[1] This leaf impression, so far as it goes, appears thus to confirm the evidence afforded by the *Ceratites* of Professor Harper, and the leaf impressions of Professor Winchell in so far as these indicate a pre-Cretaceous age for the formation.

This evidence, unfortunately, is not decisive. The plant remains found by Professor Winchell were not determined even generically; while the specimens of *Ceratites* were not found in situ in the beds in question, but "on a sand bank in the middle of the river * * * [in the area of known Cretaceous rocks] among other evidently Cretaceous fossils,"[2]

[1] Six (Rep. U. S. Geol. Surv. Terr., Vol. VIII, pp. 27-30, 1883).
[2] Proc. Acad. Nat. Sci. Phila., Vol. VIII, p. 126, 1856.

and at least one of them has since been pronounced, by no less competent an authority than Meek, "to be a worn specimen of the old genus *Ammonites*."[1]

Some better specimens from the city of Tuscaloosa were determined recently by Professor Lesquereux. They all point to the Cretaceous age of these beds, although the evidence is not yet conclusive.

In view of the diversity of opinion indicated by the foregoing review and of the paucity of organic remains in the Potomac formation and correlative deposits on the Atlantic slope, and in view of our uncertainty as to the exact equivalence of the deposits exposed on the Tuscaloosa River, we are unwilling to express ourselves decidedly as to the age of the formation to which they belong, though we incline to the belief that it is Cretaceous.

Since the formation to which the purple clays and associated strata belong is clearly distinct from those already recognized and named in Alabama and since it cannot be co-ordinated with certainty with any other formation in this country, it seems desirable that it should receive a specific designation. We therefore propose for it the name Tuscaloosa formation, after the name of the city at which and the river along which its typical exposures occur.

The stratigraphic relations of the Tuscaloosa formation may be seen by reference to the general section (Plate XXI, p. 185). In constructing this part of the section we have assumed a uniform dip towards the southwest of about forty feet to the mile. The indicated thickness is, accordingly, only approximate.

Rock Bluff.—Between Big Log Shoals and White's Bluff no rocks are seen along the river banks, except at Rock Bluff, where a pebbly conglomerate with ferruginous cement forms a bluff and, lower down the river, a rocky reef. This rock is underlaid by a gray or bluish clay. The position of this stratum is about seventy-five feet below the lowest of the Eutaw beds as exposed at Big Log Shoals.

At *White's Bluff* we see the first of a series of purple and mottled clays with interstratified sands, which occur at intervals as high up the river as Mrs. Prince's Landing, near Carthage. At the lowest estimate, these clays and sands are 275 feet in thickness.

In detail, the sections exposed along the river, in geologically descending order, are as follows:

(*a*) *Section at White's Bluff, Greene County, Tuscaloosa River.*

1. Purple clay, mottled with irregular patches of gray clay, both purple and gray portions sandy .... 10 feet.
2. Micaceous sands of light, nearly white color .... 1 foot.
3. Light colored sands, with little or no mica .... 14 feet.

[1] Rep. U. S. Geol. Surv. Terr., Vol. IX, p. 40, 1876.

A few miles higher up the river the same beds are again seen at *Steele's Bluff*, as follows:

(*b*) *Section at Steele's Bluff, Tuscaloosa River.*

1. Purple and mottled clays .... 10 feet.
2. Light colored, often nearly white, coarse grained sands, holding a few small pebbles in places; the pebbles mostly of chert, not quartz .... 10 to 12 feet.

The sands in the above section are in places strongly cross bedded and on exposure to the atmosphere show a tendency to harden into a pretty firm sandstone, which is, however, quite friable and easily rubbed down between the fingers after the thin outside coating of harder material has been removed.

At *Battle's Landing* there is a thin bed of ferruginous sandstone, extremely hard and firm and very similar to the ferruginous rocks so often formed in the drift beds.

At *Williford's Landing* the purple clay shows from the water's edge about ten feet in thickness, and over it occur second bottom or river deposits. Between the two a great number of bold springs of very pure water break out. An artesian well, said to be 400 feet deep, was bored at this place thirty or forty years ago, but no record of the boring is now to be had. The water flows out at the top and is not salty. This is the farthest north of any of the artesian wells of Middle Alabama. The locality is Sec. 31, T. 24 N., R. 4 E., in the lower edge of Tuscaloosa County.

Just above Williford's Landing and at *Bealle's Landing* there are reefs of rock forming shoals at low water. These rocks are sandstones and conglomerates, with ferruginous cement, similar to that already noticed at Battle's Landing.

We see the last outcrop along the river of the purple mottled clays at *Mrs. Prince's Landing*,[1] where they are about six or eight feet above the water's edge.

Between Mrs. Prince's Landing and Tuscaloosa the immediate banks of the river are with few exceptions formed by the loose materials of the second bottom deposits. At one or two places, however, given below, appear exposures of more ancient rocks. With a uniform dip of the strata, the distance between Mrs. Prince's Landing and Tuscaloosa would represent a thickness of more than five hundred feet, only forty or fifty of which are at all exposed along the river.

Saunders's Ferry.—At or near Saunders's Ferry, just below the Twelve Mile Rock, there is a fine exposure made by a landslide. Here are seen about thirty to forty feet perpendicular of thin, laminated clays and sands of a dark gray color, containing no recognizable fossils, but many small fragments of lignitic matter. Very similar beds have also been noticed by myself on the road from Tuscaloosa to Carrollton.

[1] They may be seen, however, above Mrs. Prince's in many places, in the hills a few rods back from the immediate banks of the river. See section (*c*), next page.

At the time of my subsequent visit to this locality certain overlying strata omitted in 1883, because considered to be a part of the drift, were added, as well as some beds, nearer the water level, at that time hidden by alluvial deposits. The full section is as follows:

(c) *Section above Saunders's Ferry, Tuscaloosa River.*

1. Rather massive clays of greenish and purple colors, breaking with conchoidal fracture. On drying, these clays become hard and rock-like, resembling then, except in color, some of the claystones of the Buhrstone formation. These clays when wet soften and slide down the slopes, covering them completely in places. In this clay we find many rounded masses of ferruginous and silicious matter of oölitic structure. Thickness of the clays ....40 feet.
2. Laminated, sandy clays, gray, with sand partings ....5 feet.
   This bed is rather more coherent than the underlying and forms a slightly projecting or overhanging ledge.
3. Gray, cross bedded sands, with partings of clay along many of the planes of false bedding ....25 feet.
   This and the preceding might readily be considered together as one member, more clayey in the upper five feet and sandier below, and this is our grouping of 1883. In these beds we find a good deal of lignitic matter and some leaf impressions very well preserved.
4. Slope or bench forty to fifty feet wide, covered by red clay and sands, slidden down from No. 1 and washed out of Nos. 2 and 3..............................3 feet.
5. Gray or whitish, cross bedded sands, forming the immediate bank of the river. 15 feet.
6. Blue, micaceous sands to water level..............................5 feet.

This section of 140 feet is undoubtedly of Tuscaloosa materials.

At *Venable's Landing* there is a sandstone bluff 15 to 20 feet high, formed of bluish, micaceous sands indurated into a tolerably firm rock in places. The bedding planes of this rock are strongly ferruginous and numbers of chalybeate springs break out from the sides of the bluff.

About five and a half miles below Tuscaloosa there are to be seen at the water's edge some rocks which consist of sandy clays somewhat indurated. These clays are interstratified with thin beds of lignitic matter, with black scales resembling graphite disseminated through it. The lignitic matter consists of indistinguishable impressions of leaves and stems, and occasionally throughout the mass are nodules of iron pyrites, and not unfrequently fragments of stems lignitized or converted into charcoal, coated externally with a thin shell of pyrite.

In the banks of the branch at the University of Alabama there is a very similar small remnant of the Tuscaloosa formation, mottled clays, embedded in the red loam. The same, mottled purple and gray, appear at several places along the road leading from the university to the city of Tuscaloosa and in the gullies back of the city toward the river. In many of these localities the clays have evidently been partly redistributed, drift fashion, but in one or two places we see the undisturbed beds, consisting of dark bluish gray, nearly black clay, in laminæ (half an inch thick), separated by partings of white sand, six or eight feet thick, with white and yellowish, strongly cross bedded sands underlying them. It is difficult to determine the thickness of these sands, as they are so hidden by the débris from above, but it is not less than 20 feet.

In one of the gullies back of Tuscaloosa we get the following section:

(d) Section in Tuscaloosa.

1. Pebbles, sand, and red loam of the Drift, forming the plateau on which the city of Tuscaloosa stands .... 15 feet.
2. Light gray, somewhat massive clays, mottled with yellow, but becoming laminated below .... 3 feet.
3. Dark blue, nearly black, laminated clays, laminæ half an inch thick, separated by thin partings of white sand. The clay contains the leaf impressions which have been examined .... 3 feet.
4. Yellowish gray, laminated clays, also containing a few leaf impressions, of rather variable thickness .... 2 feet.
5. Strongly cross bedded, yellowish or nearly white, sharp sand, with a few streaks of clay irregularly distributed through it. Thickness uncertain, but not less than .... 20 feet.

We cannot say what lies below the sands, since the strata of this formation about Tuscaloosa have suffered a great amount of denudation by erosion and their outcrops appear only here and there. The erosion hollows have been filled in with pebbles and sands of the Drift, often to the depth of 50 or 60 feet. These circumstances and the fact that the clays themselves have in places been broken up and redeposited in lumps among the drift pebbles have caused this formation to be overlooked or confounded with the Drift. The dark gray, laminated clays above mentioned contain many beautifully preserved leaf impressions which are now being studied and which will probably fix definitely the age of the formation.

It will thus be seen that the exposures along the river give us an insight into the composition of only a very small proportion of the strata which underlie the purple clays.

3. OBSERVATIONS FROM 1883 TO 1885 OF OCCURRENCES AWAY FROM THE TUSCALOOSA.

The observations made since 1883 by each of us independently and by D. W. Langdon, jr., of the Geological Survey of Alabama, have confirmed our first conclusion as to the relative positions of the various strata of this formation, and at the same time have added to our knowledge of its component parts.

The observations of Mr. Johnson have extended over parts of Autauga and Dallas Counties, on the waters of Mulberry Creek, and, in 1884, to Tishomingo and Itawamba Counties, in Mississippi. Those of the writer and of Mr. Langdon have extended over parts of Tuscaloosa, Hale, Bibb, and Autauga Counties.

To these observations are added those of Prof. A. Winchell, who describes the formation under discussion in the following terms:[1]

[1] Proc. Am. Assoc. Adv. Sci., Vol. X, Part II, p. 93, 1856.

At about eight miles above Eutaw the shale becomes softer, the lamination disappears, and we have beds of light clay, mottled curiously with blue, red, and yellow, reminding one forcibly of the Keuper of the Germans. More than this, we find along the roadsides and the margins of ravines in the upper part of Greene County large masses of red and poikilitic sandstone, exceedingly compact, and used for underpinning buildings. Add to this that very many of the artesian wells in Greene County, which penetrate these beds, furnish a constant flow of salt water, showing the occurrence of local deposits of salts, while the deepest borings have brought up abundance of quartzose pebbles, and we have four well established facts compatible with the supposition of the Triassic age of these beds, without mentioning the occurrence of vegetable remains, some specimens of which appeared to me indistinctly allied to stems of *Equisetites*.

These beds continue without much change to the very suburbs of Tuscaloosa; and a very good section is seen at Foster's Ferry, within a few miles of town.

The almost total absence of organic remains from these shaly and poikilitic deposits renders the determination of their age extremely uncertain.

It seems probable that the red sandstone mentioned by Professor Winchell is the same as that occurring at Battle's Gin, on the river, and at Havana, presently to be described.

On going by land from Tuscaloosa to Eutaw, on the western side of the river, in 1886, we have been able to repeat the observations of Professor Winchell. Two miles west of Saunders's Ferry and about ten miles west of Tuscaloosa, the road passes by the edge of a great gully washed out of materials of the Tuscaloosa formation. This gully is of nearly 100 feet perpendicular depth, and the bottom slopes then very gradually down 40 or 50 feet more.

(*a*) *Section of gully 10 miles west of Tuscaloosa.*

1. Drift and red loam .... 10 feet.
2. Sharp, yellowish, cross bedded sands, with strings of light yellow, chert pebbles, subangular and in many cases showing casts of encrinital buttons and bryozoans and other sub-Carboniferous fossils .... 20 to 25 feet.
3. White and red, laminated clays of very irregular thickness, often discontinuous .... 5 feet.
4. Firm, yellowish sands .... 12 feet.
5. Bed of subangular, white and yellow chert pebbles, with sub-Carboniferous fossils .... 2½ feet.
6. Red clay in irregular beds or pockets .... about 3 to 4 feet.
7. Yellowish white sands, with thin streaks of pebbles .... 8 feet.
8. Red clay and sand .... 1 foot.
9. Strongly cross bedded, yellow sands, with thin, irregular sheets of clay following some of the lines of false bedding .... 35 feet.

Below this, cross bedded sands with clay partings continue to the lowest part of the gully, probably 40 feet below the above section.

From this place down to Knoxville nearly every hill reveals the materials of this formation, consisting mainly of yellowish and reddish, cross bedded sands, with clays (red and purple) sparingly interspersed. The section of the gully above given might be taken as typical of the strata exposed over this entire distance.

In places the sands are cemented by iron into quite firm sandstones, which are quarried for rough work. The rock can be easily cut when freshly dug, but it soon hardens on exposure. I am strongly inclined to believe that the red sandstones and conglomerates seen at Battle's Gin, above Williford's Landing, near Havana, &c., are bedded rocks of this formation; at any rate the constituent sands are of this age, while the induration into rocks by the ferruginous solutions may have occurred in comparatively recent times.

A short distance south of Knoxville we lose sight entirely of the red and purple clays which have been to us a characteristic of the Tuscaloosa formation, and begin to encounter the glauconitic, cross bedded sands, laminated clays, and other materials which we have classed with the Eutaw formation. If we assume a dip of 30 or 40 feet to the mile, estimating from the width of outcrop, there will be some 900 feet or more of the Tuscaloosa and 300 to 400 feet of the Eutaw formation. In both, these materials have been deposited under almost identical conditions, except that at the base and at the summit of the Tuscaloosa formation we find heavy beds, 40 feet or more in thickness, of massive clays of red, purple, and greenish colors, and also sparingly interspersed through the whole of the formation are thinner beds of similar clays. No beds of this character have been observed in what we have called the Eutaw formation, the only beds of which, other than sands, are thin, laminated gray clays, with partings of sand.

The pebbles of the Tuscaloosa formation are, as a rule, subangular, of chert, and in many cases fossiliferous; those of the Eutaw, well rounded, of quartz, and non-fossiliferous, so far as our observations go. The cross bedding of the sands in the Tuscaloosa formation is much less pronounced than in the Eutaw, as if effected in less rapidly flowing waters. The two formations are further alike in the circumstance that their only fossils are leaf impressions and lignitized trunks, the marine fossils in the sands just below the Rotten Limestone characterizing the transition beds which have been named "Tombigbee Sand" by Dr. Hilgard.

One may well hesitate to separate very widely these two formations, whose strata were deposited continuously and under very similar conditions and contain the same character of fossil remains, until a thorough study of the leaf impressions and other fossils shall have established their positions in the geological scale. In our southern post-Tertiary Drift, our Eutaw, and our Tuscaloosa formations we have three groups of very similar strata, whose distinctive characters it is difficult, if not impossible, to describe in words, since there are cross bedded sands with interspersed sheets and beds of clay and pebbles in all three; yet in the field the differences are so easily recognized in the topography, the timber, in the color and other qualities of the soils, &c., that we are never long in doubt as to which formation we have under consideration.

A few miles south of the village of Havana on the Greensborough road begin the yellowish red, glauconitic, cross bedded sands of the Eutaw group, which extend down to Greensborough.

GULLY IN SANDS OF THE TUSCALOOSA FORMATION, NEAR HAVANA, HALE COUNTY

Just north of the first appearance of these cross bedded, glauconitic sands, near the residence of Hon. A. M. Avery, there are several very deep gullies near the road where the upper beds of the Tuscaloosa formation are beautifully exposed (Plate IX). These beds are as follows:

(*b*) *Section two miles south of Havana, Hale County.*

1. Red surface loam, forming exceedingly fertile soil ....10 to 15 feet.
2. Yellow sands and pebbles, conformable in stratification with the underlying strata ....10 to 12 feet.
3. Purple and pink, micaceous, argillaceous sands, most beautifully cross bedded, 20 to 30 feet.

That these deposits lie very near the summit of the Tuscaloosa formation is evident from the fact that the cross bedded, glauconitic sands of the Eutaw formation occur at the surface only a very short distance to the southward. The red loam forming the uppermost of the section resembles in some degree the usual red loam of much of the southern part of the State, except that it is of much deeper color and apparently more fertile than most of these loams. It may be derived from the disintegration of the glauconitic sands of the Eutaw formation or from the uppermost of the Tuscaloosa formation. The pebble bed No. 2 resembles also in some degree the pebble beds of the Drift, but as it is entirely conformable in stratification with the underlying beds (a circumstance of rare occurrence in the Drift) I am inclined to consider this bed also as a part of the Tuscaloosa formation. The sands No. 3 differ from anything which occurs in the Drift, and I have seen the like only at one other place, viz, on Mulberry Creek, in Autauga County, near the residence of Hon. James W. Lapsley.

North of Havana the underlying beds of this formation are exposed in the following order: At Havana, and appearing at intervals for several miles northward, there is a thick bed of ferruginous conglomerate, best seen in a ravine back of the town of Havana, where it forms perpendicular bluffs ten to twelve feet in height at the top of the ravine. Large masses of the rock have split off from time to time and have rolled down into the gorge below.[1] It has been impossible thus far to determine whether to refer this conglomerate to the Drift or to the Tuscaloosa formation. Its great extent and its persistence seem to favor the supposition that it belongs to the older formation, yet it is in appearance quite similar to a conglomerate of very common occurrence in the

[1] Underneath the ledge of rock shallow caves have been washed out, and in these flourish several rare ferns, especially *Asplenium ebenoides* Schw., which was discovered here by Miss Julia Tutwiler and is interesting from the fact that it is known to occur elsewhere only along the banks of the Schuylkill River. Besides this fern, there are *Camptosorus rhizophyllus* or walking leaf, *Trichomanes radicans*, and *Aspedium marginale.* The appearance of this conglomerate and the ferns growing in the shallow caves beneath it recall very forcibly the Carboniferous conglomerate which forms the surface over so great a part of the counties of Marion and Winston.

Drift everywhere. I do not know, however, of any similar Drift formation approaching this in the thickness of the rock.[1]

On the south side of Big Sandy Creek we get again a very good section of the purple clays which form the lower members of the Tuscaloosa formation, as follows:

(c) Section on Big Sandy Creek, Tuscaloosa County.

1. Purple and mottled clays like those occurring at Steele's Bluff, on the Tuscaloosa River .... 30 feet.
2. Light yellow sands, with pebbles, also similar to those seen at the above named locality and at White's Bluff .... 10 to 15 feet.
3. Gray, laminated clay, inclosing a lignitized tree trunk, at base of hill ... 4 to 5 feet.

Farther along the road the thickness of the purple clays is seen to be at least 50 feet and they crop out along the hillsides for a good many miles. It is easy to recognize them even without close examination, for wherever they come to the surface in the roads it is necessary in wet weather to lay down a causeway, since the tenacity of the clay is so great that the road would otherwise be impassable.

About seven and a half miles from Tuscaloosa, where the Greensborough road crosses Little Sandy Creek, we get an exposure of what we suppose to be still lower members of the formation. This section was first examined in 1884 by Mr. Langdon. It is as follows:

(d) Section on Little Sandy Creek, Tuscaloosa County.

1. Micaceous, yellow sands, including a thin streak of gray, lignitic clay, with small pieces of lignitic matter .... 10 inches.
2. Gray, laminated clays, highly micaceous .... 6 feet.

Between the two branches of Sandy Creek the purple and mottled clays appear upon nearly every hillside. North of Little Sandy Creek we see no more of the strata of this formation along this road.

In November, 1884, D. W. Langdon, jr., made a study of this formation in Bibb County, and in 1885, in company with Mr. Langdon, I examined its outcrops in the western part of Autauga County and the adjoining parts of Dallas and in those parts of Bibb and Tuscaloosa Counties lying between the towns of Tuscaloosa and Randolph.

In the western part of Autauga County, near the post office, Vineton, there are several exposures of the upper beds of the Tuscaloosa formation, shown in the following sections:

(e) Section near Col. J. W. Lapsley's, near Vineton, Autauga County, No. 1.

1. Stratified clays of white, pink, and purple colors, interlaminated with thin sheets of yellow sands; the lower 8 feet of this bed have a larger proportion of sands .... 10½ feet.
2. Gray, laminated clays, with partings of purple sands .... 5 feet.
3. Yellowish white, laminated clays, with purple and other bright colors on the dividing planes, 5 feet showing; but the same beds appear to continue down the hill for at least 10 feet farther .... 15 feet.

[1] A careful comparison of the pebbles should be made.

At another locality near Colonel Lapsley's, in a gully, we see the following section:

(*f*) *Section near Col. J. W. Lapsley's, No.* 2.

1. Yellowish sands, beautifully cross bedded ....4 feet.
2. White and pink clays, interbedded with yellow sands.........................10 feet.

Along the road leading from Colonel Lapsley's to the railroad station (Jones's switch), we get another section of the strata represented in the first section above, together with some underlying beds. In the upper part, these beds, being exposed along a road, are much stained, so that it is impossible to correlate them, foot by foot, with those exposed in Section 1, although they have about the same altitude and are distant from each other only about half a mile.

Below some 40 or 50 feet of red loam containing fragments and bowlders of ferruginous sandstone, such as characterizes the Drift formation we get the following section:

(*g*) *Section near Col. J. W. Lapsley's, No.* 3.

1. Purple clays, interbedded with reddish sands..6 feet.
2. Mottled (red and yellow), sandy clays, partly obscured by overlying drift, pebbles, and sands..12 feet.
3. Red sands, containing small, lenticular bits of yellow clay ....5 feet.
4. White and yellow laminated clays..6 to 8 feet.
5. Strata not seen ....10 to 15 feet.
6. Variegated, micaceous, and slightly argillaceous sands, strongly cross bedded; colors, bright and sharply defined, pink, dark purple, yellow, and red..5 to 6 feet.

The strata of bed No. 6 are identical in appearance and in composition with the variegated sands exposed in the gullies at Mr. Avery's, near Havana, in Hale County, above described. I did not notice here the yellow sands with pebbles immediately over the variegated sands, but they may have been in the division No. 5, here obscured by surface materials.

Across a small ravine from this section, the yellow sandy clays have been washed for yellow ocher, the beds occupying about the same position as Nos. 2, 3, and 4 of the preceding:

(*h*) *Section at the ocher beds, near Vineton.*

1. Yellowish red, cross bedded sands, inclosing thin streaks of purple clay ....6 feet.
2. Yellow, sandy clay, from which the ocher is obtained...........................16 feet.

The sand makes about 80 per cent. of the above bed, and the ocher is obtained from it by washing. The ocher is of excellent quality and of bright yellow color.

Nearly 100 feet below the lowest of the beds of Section 3 we see in the banks of Mulberry Creek, just below the iron bridge, the following section:

(*i*) *Section on Mulberry Creek, near Vineton, Autauga County.*

1. Mottled, purple clays, similar to those at Steele's Bluff, on Tuscaloosa River.5 feet.
2. Yellow, cross bedded sands ....3 feet.
3. Mottled clays, sandy below..5 feet.
4. Grayish white, micaceous sands, with irregular patches of red and yellow colors ....4 feet to water.

This whole section is identical in appearance with that seen at White's Bluff and at Steele's Bluff.

From Vineton up to Randolph very little can be seen of the strata of the Tuscaloosa formation until within three miles of the latter place, where the dark purplish gray clays, which seem to lie near the base of the formation, are encountered. These clays are undistinguishable from those above described between the two branches of Sandy Creek in Tuscaloosa County.

Between Randolph and Centreville we get several very good sections of the beds under consideration, as follows:

(*j*) *Section at Soap Hill, 7 miles east of Centreville, Bibb County.*

1. Purple, mottled clays at summit of hill ....5 feet.
2. Clayey sands in several ledges ....10 feet.
3. Cross bedded, yellowish and whitish sands, traversed at intervals by ledges of sandstone formed by the induration of the cross bedded sands..30 feet.
   The thickest of the above sandstone ledges is about 3 feet.
4. Laminated, gray clays, with partings of sand..10 feet.
5. Alternations of laminated, gray clays and cross bedded sands in beds of 12 to 18 inches thickness ....40 feet.
6. Yellowish, cross bedded sands, with clay partings..20 feet.
7. Laminated, gray, sandy clays, containing a few leaf impressions, which are, however, not distinct enough as a rule to permit perfect identification..10 to 15 feet.
8. Grayish white sands ....8 feet.

In this section the first three members are best seen on the eastern slope of the hill and Nos. 7 and 8 in a gully on the eastern side of the hill. The intervening members are most clearly exposed on the western descent of the hill, nearly a mile from the first locality.

Between four and five miles east of Centreville a part of the preceding section is repeated.

(*k*) *Section 4 to 5 miles east of Centreville, Bibb County.*

1. Gray and reddish, sandy clays ....15 feet.
2. Ledge of sandstone showing cross bedding ....3 feet.
3. Whitish sands and clays..4 feet.
4. Nearly white, cross bedded sands ....25 to 30 feet.

The hill in the eastern part of the town of Centreville contains a good deal of reddish, mottled clays, probably of this formation. These clays may be seen again about half way between Centreville and Scottsville, where they appear to overlie the strata of the Lower Silurian and Carboniferous formation. Between Scottsville and Tuscaloosa these beds are seen at several localities.

About twelve miles east of Tuscaloosa the grayish purple clays similar to those described between the two branches of Sandy Creek appear in many places along the slopes of hills where they are laid bare by the road.

(*l*) *Section 10 miles east of Tuscaloosa.*

1. Ferruginous sandstone in sheets ....6 to 8 inches.
2. Variegated, clayey sands holding small pieces of purple clay. The sands show chocolate, purple, red, and yellow colors..6 to 8 feet.

3. Purple clays, with partings of sand; similar to the purple clays south of Tuscaloosa ....10 feet.
4. Ledge of ferruginous sandstone..................................1 foot or more.
5. Laminated, gray and yellow, sandy clays or clayey sands, yellow at top and shading into gray at bottom...6 to 8 feet.
6. Lignite, with pyrite nodules ....2 to 6 inches.
7. Dark gray, somewhat massive clays, becoming lighter below...........6 to 8 feet.
8. Strata obscured by washings from above......................................20 feet.
9. Purple clays at base of hill...undetermined.

In some places near this, five feet of purple clays are seen overlying No. 1 of the section.

About nine miles east of Tuscaloosa about 30 to 40 feet thickness of purple clays is seen along a hillside. In these clays there are two ledges of ferruginous sandstone or, perhaps more properly speaking, of sandy iron ore. The clays are a mixture of purple and yellow and appear to form the lower strata of the hill for 20 or 30 feet below those above described. The iron ore which covers so much of the slope of this hill is somewhat sandy, occasionally quite pure and compact, giving a red streak. It differs very materially from the usual limonite of the valleys.

At the Box Spring, about five miles east of Tuscaloosa, the railroad cut exposes 6 to 8 feet of laminated, gray clays marked with purple streaks. Immediately above these is a very persistent ledge of ferruginous sandstone and over that 10 or 12 feet of drift and loam of recent date.

About four miles east of Tuscaloosa we see the summit of a rounded mass of the strata of this formation, consisting of 2 or 3 feet of purple, gray, and variegated, laminated clays, underlaid by about the same thickness of cross bedded sands. This exposure lies plainly unconformably embedded in the red loam of the Drift.

4. OBSERVATIONS IN MISSISSIPPI.

In 1884 Mr. Johnson, on his reconnaissance of Tishomingo and Itawamba Counties, in Mississippi, saw beds of lignite and tough, laminated clays which he, at the time, referred to a formation below the Eutaw (our Tuscaloosa). This lignite was traced by him the whole length of Reed's Creek (between the Tombigbee at Fulton and Bull Mountain Creek). At several localities, viz, at Maxey's Old Mill, Sec. 9, T. 10 S., R. 9 E., he collected many fine leaf impressions. The lignite here was two feet thick. At Reed's Mill and at Chaney's, Secs. 20 and 17, in T. 10 S., R. 9 E., many phytogene fossils were collected, and these localities were remarkable for the fine, jet-like appearance of the lignite. A jet of this kind was also found by Mr. Langdon in Centreville, Bibb County, Alabama. At Barnard's Bluff on the Tombigbee, the lignite appears again embedded in characteristic clays of the Tuscaloosa formation.

Mr. Johnson also calls attention to the gravel beds which occur in this part of Mississippi, and which, according to my observations, have their counterpart in Marion, Colbert, and Franklin Counties, Alabama.

The materials of these gravel beds are mostly cherty, subangular, and quite different from the usual quartz pebbles of the Drift. Associated with these are the so-called kaolin beds and the deposits of pulverulent silica. The pebbles as well as the silica are evidently derived for the most part, if not entirely, from the fossiliferous chert of the sub-Carboniferous formation of that region. Mr. Johnson expresses the opinion that these pebble beds of chert underlie the newer, stratified, glacial drift deposits without being a part of the same. Wherever the pebble beds occur in the Cretaceous or sub-Cretaceous clays of Tishomingo and Itawamba Counties, in Mississippi, there is a prevalence of these cherty characteristics. In this connection we may also refer to the fact that the pebbles seen in the Tuscaloosa sands at White's Bluff and at Steele's Bluff on the Tuscaloosa were of chert and not of quartz.

IV. SUMMARY OF THE LEADING FEATURES OF THE CRETACEOUS STRATA OF ALABAMA. (PLATE XXI.)

Under this heading, while making a distinction between the two, we include both the strata of undoubted Cretaceous age and those of as yet undetermined but probably Cretaceous age.

CRETACEOUS STRATA.

The whole thickness of unquestioned Cretaceous rocks in the western part of Alabama, according to our measurements and estimates, is between 1,550 and 1,575 feet, and the group has been divided into three formations, which are (1) the Ripley, (2) the Rotten Limestone, and (3) the Eutaw.

1. *The Ripley formation.*—We cannot give the absolute thickness of this formation, but it will in all probability fall between 250 and 275 feet. The strata are, first, 55 to 60 feet of yellow sands,[1] in some localities containing many Cretaceous shells, followed by 100 feet of dark gray, nearly black, micaceous, sandy clays or clayey sands, traversed by hard ledges of similar materials, and, along the two rivers at least, not prolific of fossil remains. Then 30 to 35 feet of bluish, argillaceous limestones, with great numbers of Cretaceous fossils, which are, however, mostly in the form of casts and generally phosphatic. Below this, again, a mass of sands (60 feet or more) of various colors, with indurated bands of sandstone running through it.

2. *The Rotten Limestone.*—In this we have the most massive of the calcareous formations of Alabama, outside of the Paleozoic. The thickness is about 1,000 feet, and there is surprising uniformity in the material, which is an impure, argillaceous limestone, merging in places into a calcareous clay. Where the clay predominates, we usually find the

[1] We have recently found conclusive evidence that the yellow sands are merely a modification produced by oxidation of the gray sandy clays next below.—E. A. S.

greatest abundance and variety of fossils. The strata of the Rotten Limestone form the bluffs along great stretches of both rivers.

3. *The Eutaw formation.*—This formation has a thickness of not less than 300 feet. At the base of the Rotten Limestone we find some 20 to 25 feet of calcareous sands and greensands, in part strongly phosphatic, containing a large number of fossils, many of which are in the form of phosphatized casts. This bed forms a transition between this and the next succeeding formation. We place it with the Eutaw formation for the sake of convenience, with the remark that an examination of the fossils may hereafter show that it is more closely related to the Rotten Limestone.

Below these phosphatic sands are yellowish, cross bedded sands, 40 to 50 feet, and laminated, blue clays alternating with glauconitic sands for 40 feet more. The rest of the strata, to the base of this division, consist of laminated and cross bedded sands and laminated clays in many alternations, interbedded at intervals with lignitic strata consisting of lignitized twigs and trunks of trees, but not, so far as yet known, of beds of lignite. With these are one or two thin beds of pebbles. As before stated, the exact thickness cannot be given.

STRATA OF UNDETERMINED AGE, PROBABLY CRETACEOUS.

The Tuscaloosa formation.—Below the lowermost of the undoubtedly Cretaceous beds is found a great thickness of clays and sands of as yet undetermined age. These appear at intervals along the banks of the Tuscaloosa or Warrior River from Big Log Shoals up to the city of Tuscaloosa. Assuming a uniform dip of some 40 feet to the mile, the thickness of this formation will be about 1,000 feet. We cannot as yet give the order of succession of the various strata, which are mottled, purple, and gray clays, yellowish and gray sands, pink and light purple sands, and thinly laminated, dark gray clays, which contain impressions of leaves in considerable numbers and sometimes in a state of preservation perfect as to form and markings.

V. UNDULATIONS AND FAULTS IN THE TERTIARY AND CRETACEOUS STRATA OF ALABAMA.

TERTIARY STRATA.

The average seaward dip of the Tertiary strata of Alabama is about twenty-five or thirty feet to the mile, but there is at many points a wide departure from this uniformity. Professor Tuomey appears to have been the first to direct attention to this circumstance. In speaking of the Buhrstone at the Lower Salt Works, in Clarke County, he remarks:

> We have here, then, an interesting example of the sinking of strata below the surface and of their rising again. The beds exposed at Baker's Bluff, and still higher on the river, as well as on Bashi Creek, after being depressed beneath Saint Stephens and a portion of Clarke County, make their appearance again at this locality, and probably still farther west.[1]

[1] First Bien. Rep. Geol. Ala., p. 150, 1850.

As intimated in another part of the present publication, these observations of Professor Tuomey were confirmed by us in 1883, and my subsequent investigations have further shown the existence of more than one well marked fold in the strata of this part of the State.

On another page we have said that the Buhrstone rocks which dip below the surface a short distance south of Wood's Bluff, in Clarke County, rise again at Hatchetigbee Bluff and at Jackson, and from this place an almost continuous outcrop of these rocks may be followed southward as far as the Lower Salt Works. These points appear to mark the summits of at least two distinct anticlines, and a third is marked by Lower Peach Tree, on the Alabama River, while the unequal surface distribution of the beds of the Lignitic formation, lying to the northward of the localities above named, leads one to suspect the existence of several other folds, notably one involving the black clays of the Black Bluff group along the Tombigbee River, another concerning the *Gryphæa thirsæ* beds in the central part of Marengo County and in the Grampian Hills region of Wilcox County.

We have determined approximately the limits of the Hatchetigbee anticlinal and of the Lower Peach Tree fold and its associated fault in the immediate vicinity of the Alabama River. We have also followed a line of uplift from near Jackson down to the Lower Salt Works in Clarke County. In what follows we give some details of the observations on which our knowledge of these undulations is based and we also append a few notes concerning the irregularities in the surface distribution of the Buhrstone and the underlying beds of the Lignitic in Monroe and Conecuh Counties.

(1) THE LOWER PEACH TREE ANTICLINE.

In ascending the Alabama River we find the Wood's Bluff marl at the water level at Johnson's wood yard, a few miles below Bell's Landing. At the latter locality a marl bed, which is about 115 to 120 feet below the Wood's Bluff marl, and which we have called the Bell's Landing marl, is some 25 or 30 feet above water level. Nine miles farther up the river, at Lower Peach Tree, this bed is 100 feet above water level, while at Yellow Bluff, several miles still farther up the river, it is seen within 10 feet of water level, and the Wood's Bluff marl appears about 115 or 120 feet above it on the hillside immediately back of the river bluff.

Above Yellow Bluff the river makes a bend towards the southeast so that the Wood's Bluff marl is not seen again along its banks in this direction; at Bethel, however, a few miles west of Yellow Bluff, we see the Wood's Bluff marl and the *Gryphæa thirsæ* beds, which are separated by at least 250 and probably by over 300 feet of strata, coming to the surface within half a mile of each other and not more than 120 feet hypsometrically apart. This disposition of things appears to show that just north of Bethel there is either a very abrupt change in the angle of dip of the strata or a stratigraphic break. I have examined the ground very carefully on several occasions, and have failed to see any evidence of high angle of dip, but, on the contrary, have obtained the clearest evidence of the existence of a fault of nearly 200 feet vertical displacement, traced from Bethel across the river to Black's Bluff, and it probably extends much farther in each direction from these limits. We shall call this the Bethel fault and give below some details of its occurrence.

The Lower Peach Tree fold.—The geographic limits of the Lower Peach Tree fold, so far as we have determined them, have been fixed by the following data: Across Choctaw County, the Wood's Bluff marl occupies a narrow strip of surface; at Wood's Bluff, on the Tombigbee, and at Cade's Bend, a mile or two above, it appears at the water level, showing a nearly horizontal position. This may be the beginning of the fold, which, beyond Choctaw Corner, eastward, broadens out till at the Alabama River it spreads over an expanse, north and south, of 10 miles or more. In the vicinity of the river, however, its occupation of the surface is not continuous, but the underlying beds of the Bell's Landing series come in and make the intervening country between its two exposures, the one south of Lower Peach Tree, the other in the vicinity of Bethel and Yellow Bluff. In its longer dimension, therefore, this fold appears to rise about the Tombigbee River near Wood's Bluff and to extend with constantly increasing elevation to the Alabama River, Lower Peach Tree occupying the summit of the roll, which has its widest cross section along the Alabama River. Eastward from this river, I have followed, with the exception noted below, a single outcrop only of the Wood's Bluff marl across Monroe County along the course of Flat Creek, and this is the continuation of the lower of the two outcrops of the bed above spoken of, as exhibited in Wilcox County west of the river and south of Lower Peach Tree, while, of the northern or Bethel outcrop, I have seen only one occurrence east of the river, viz, near Black's Bluff. This is no doubt in great measure due to the fact that there is on the eastern side of the river, opposite Yellow Bluff, a good deal of low country from which the older strata have been removed by denudation.

This fold involves, so far as concerns their surface outcrop, the Bell's Landing, the Wood's Bluff, and the Hatchetigbee series of the Lignitic, for the clays of the latter series are to be seen overlying the Wood's Bluff marl in the hills west of Yellow Bluff. I have not seen any evidence either of the broadening or of the duplication, by reason of this fold, of the outcrops of the Buhrstone rocks which immediately overlie the Hatchetigbee beds.

To summarize, we can trace this anticline in the direction of its axis from Wood's Bluff, on the Tombigbee River, across Clarke County, to the Alabama River, where it has its greatest elevation and its broadest cross section; beyond the river, eastward, we have traced it as far as

Black's Bluff. The northern limit of this fold, in the vicinity of Bethel, is a fault of at least 200 feet displacement, length not ascertained, already mentioned above.

The Bethel fault.—To obtain a clear idea of this fault it is necessary to recall the stratigraphic relations of the several subdivisions of the Lignitic which it involves. The Wood's Bluff marl, with its indurated limestone bowlders and its characteristic fossils, is our best landmark. Above this marl lie the sandy clays of the Hatchetigbee section, 175 feet in thickness. These latter beds are only slightly concerned in the fault. Below the Wood's Bluff marl we have about 120 feet of sandy clays and clayey sands, the upper 75 feet of which hold several beds of lignite, and then another marl bed, the Bell's Landing marl. Below this marl we have at Lower Peach Tree about 100 feet of gray sandy clays containing two marl beds (Gregg's Landing marl being the upper of the two). In these sections, therefore, we have over 400 feet of strata, the exact relations of which are clearly seen at Yellow Bluff and at Lower Peach Tree.

The Nanafalia section consists at top of 50 feet or more of gray, sandy clays, showing a great tendency to indurate into hard rocks, resembling the Buhrstone, to which, for convenience, I give the name *pseudo-Buhrstone.* Below the pseudo-Buhrstone are at least 80 feet of sandy strata, characterized by the presence of *Gryphæa thirsæ*, and below these still, about 70 feet of cross bedded, glauconitic sands, with a few obscure fossils in the upper part, and a bed of lignite, from four to seven feet in thickness, near the base. As we have already intimated several times, we have seen no exposures which exhibit both the Lower Peach Tree beds and the pseudo-Buhrstone, so that it has been thus far impossible to determine the dimensions of the gap between the base of the Bell's Landing (at Lower Peach Tree) and the summit of the Nanafalia section (at Gullette's Landing); and the Bethel fault, coming as it does exactly at this place in our geological scale, serves to complicate matters still more. In estimating the vertical displacement caused by the fault, there is always the unknown quantity embraced in this gap to be considered, and our estimates are to be taken as exclusive of this unknown quantity.

Following are given some details concerning the fault. At Bethel, SW. ¼ of Sec. 35, T. 12 N., R. 5 E., the Wood's Bluff marl occupies the summit of the hills, and about half a mile north we find the *Gryphœa thirsœ* beds. The Wood's Bluff marl may also be seen on most of the hills between Bethel and Yellow Bluff and at the latter place, and a line drawn from Bethel to Yellow Bluff will just about define the limit of the marl towards the east. As we descend towards the east from any of these hills, capped with the Wood's Bluff marl, we come directly, and usually within 50 feet vertical distance, upon the pseudo-Buhrstone, and 60 or 70 feet below that upon greensands holding *Gryphœa thirsœ.* Near Bethel towards the southeast then the fault brings together, or rather within 50 feet of each other, the Wood's Bluff marl and the pseudo-Buhrstone, a displacement, taking no account of the gap between the Bell's Landing and Nanafalia sections, of more than 150 feet. At Yellow Bluff, as we have seen in foregoing pages, there are exposed all the strata from the Wood's Bluff down to the Bell's Landing marl. Up the river, within half a mile of the landing, this marl dips below the water level. Less than half a mile farther up the river, beds of *Gryphæa thirsæ* appear in the left bank. Here some of the beds overlying the Bell's Landing marl are brought together with *Gryphæa thirsæ* beds, a displacement, as before, of 175 feet or more. Again, across the river, on the plantation of Mr. James Tait, Sec. 24, T. 11 N., R. 6 E., near Black's Bluff, we find the Wood's Bluff marl forming the second bluff, about 100 yards from the river, while the lower beds of *Gryphæa thirsæ* marl, Nos. 10, 11, and 12 of the Gullette's Bluff section, make the immediate bank of the river. In this case the strata between Wood's Bluff and Bell's Landing marls (120 feet), those below the Bell's Landing marl at Lower Peach Tree (100 feet), the pseudo-Buhrstone (50 feet or more), and about 30 or 40 feet of the *Gryphæa thirsæ* beds have been engulfed, a displacement of not less than 300 feet, leaving out of account, as before, the gap mentioned. We have traced the fault from Bethel to Black's Bluff, a distance of 10 miles or more. Eastward from Black's Bluff, near where the Camden road crosses Gravel Creek, on Yankee Branch, a thick bed of lignite (4 feet or more) occurs immediately and to all appearances conformably below beds of *Gryphæa thirsæ*. The Coal Bluff lignite has above it some 60 feet or more of glauconitic sands, separating it from the *Gryphæa thirsæ* beds, so that this contact of two unusually widely separated beds (if this be the Coal Bluff lignite) could only be brought about by some kind of displacement. And lastly, at Black's Bluff we have a thick bed of lignite in contact with the *Gryphæa thirsæ* beds. From its close proximity to the Wood's Bluff marl (at the line of fault above described), one would be inclined to consider this as one of the lignites of the Wood's Bluff series but for its thickness. The certain identification of these lignites and their relations to the Bethel fault we have still to work out.

(2) THE HATCHETIGBEE ANTICLINE.

The axis of this fold, like that of the preceding, has a northwest-southeast direction. At the southeastern end and also at the northwestern it sinks gradually to the level of the undisturbed beds. It may be traced from near Nicholson's Store, in Choctaw County, across that county, through Bladen Springs, into the northeastern corner of Washington County at Hatchetigbee Bluff, and thence across the river for about ten or twelve miles into Clarke County. It is about twelve miles across in its widest part, i. e., from Coffeeville southwestward. It involves, so far as concerns their surface exposure, the following strata: The White Limestone, the Claiborne, the Buhrstone, and the Hatchetigbee beds, aggregating, with the exclusion of the White Limestone, about 500 feet of strata. It appears to have exerted no influence upon the direction of the drainage.

In the following routes we obtain the data from which we have outlined this fold:

First. From Jackson to Coffeeville and thence northward to Wood's Bluff. On this road, 6 miles north of Jackson, the first well defined outcrop of Tertiary rocks is encountered. These rocks belong to the Buhrstone, but before reaching them the presence of the Claiborne beds at no great depth below the surface is very clearly revealed in the frequent occurrence of patches of the characteristic red, limy clays produced by the action of these beds upon the red loam. Beyond this the sands and clays of the underlying Hatchetigbee group are seen along the slope leading down to the crossing of Jackson's Creek. By turning eastward from this place the Claiborne sands, with their characteristic fossils, can be seen on Stave Creek, in Secs. 8 and 9 of T. 7 N., R. 2 E. This I take to be the southeastern limit of the anticline, for looking eastward and southeastward from this place we see nothing but the characteristic landscape of the Lime Hills region. Proceeding northward, the Buhrstone rocks are again encountered about eight miles from Coffeeville, and they extend thence to within five miles of that place. The limit of the anticline in another place, southeast of Coffeeville, is ascertained by going northeastward from Salitpa post office, which is on the Hatchetigbee formation in Sec. 31, T. 8 N., R. 1 E., towards Dead Level, in Clarke County. In this direction the Buhrstone is crossed between three and five miles from Salitpa post office. Coffeeville itself is upon the Claiborne, and going northward we pass first into the White Limestone, and at Turkey Creek, near the northern limit of T. 10 N., R. 2 W., into the Buhrstone, the Claiborne as usual making very little show upon the surface, except in the red, limy clays above noticed. The Buhrstone ridge just alluded to becomes very prominent at White Bluff, and from that place an uninterrupted view may be had of all the underlying strata down to the Wood's Bluff group. In this route, therefore, we pass over the anticline between Jackson and Coffeeville and over a syncline, with White Limestone as the uppermost formation, between Coffeeville and White Bluff, while by diverging eastward in two or three places the eastern limits of the anticline can be pretty accurately determined.

Second. On the western side of the river the anticline is equally well marked along the route from Saint Stephens, through Bladen Springs, to Butler, in Choctaw County. On this road the White Limestone may be seen to within nine miles south of Bladen Springs; then occurs a strip of pine lands, in which the underlying Claiborne formation is not often clearly seen. At one place, however, near the road in the northeast corner of Sec. 29 (corresponding to Sec. 27 in the ordinary townships)[1] T. 8 N., R. 2 W., about a quarter of a mile west of the Tony Rail place, in the bluff over a spring, about six feet of the Claiborne sands are exposed. The upper part of this exposure is a mass of shells packed in a yellowish red sand, as at Claiborne; the lower part at the water level is a hard, greensand filled with shells, as at Pugh's Branch, in Clarke County. *Crassatella protexta* is here the commonest shell; but *Melongena alveata*, *Monoceros armigerus*, *Ancillaria subglobosa*, *A. scamba*, *A. staminea*, and other Claiborne forms are also abundant. This locality is about a quarter of a mile north of the last Lime Hill. Beyond this, towards Bladen Springs, the Buhrstone rocks are first seen at the bridge across Sinta Bogue in the northwest corner of Sec. 14, T. 8 N., R. 2 W., six miles from the springs, and they continue up to within two miles. About the central part of this outcrop, four miles from the springs, there is a marl bed several feet in thickness, containing great numbers of a shell closely allied to *Ostrea sellæformis*. This marl is found just below a hard ledge of claystone, and in the fields near by lie many fragments of rock filled with silicified Claiborne shells. The springs are upon the upper Hatchetigbee beds, for going northwards the Buhrstone is again met in the hills about two miles north of the springs, and outcrops along this road for about four miles. Beyond this Buhrstone belt we come upon the Claiborne sands on the hill just south of Souilpa Creek, and going down the hill we see the *Ostrea sellæformis* beds, and in the immediate bank of the creek the bed of comminuted shells in a matrix of greensand, precisely like that in the lower part of the Claiborne bluff and at Coffeeville landing. At Barryton Mill, about the northeast quarter of Sec. 13, T. 10 N., R. 3 W., about a mile east of the road we are now describing, this bed of comminuted shells, with numbers of large and perfect shells of *Ostrea sellæformis*, forms the bed and banks of the creek. To the westward also of this road the banks and channel of Oaktuppah Creek are formed of the lower Claiborne beds, which outcrop again on the hills some four miles north of the creek. The belt of Claiborne beds is crossed on this road from the southern banks of Souilpa Creek northward about seven or eight miles. This great width of outcrop is due to the fact that the beds form a shallow synclinal basin. This basin holds a narrow belt of White Limestone, which may be traced from Womack Hill, SE. ¼, Sec. 4, T. 10 N., R. 2 W., northwestward to the Mississippi line at Nicholson's Store. The outcrop of White Limestone at Womack Hill is about two miles long and one hundred or two hundred yards wide. Then northwestward in Mrs. Nix's field, Sec. 2, T. 10 N., R. 3 W., is another outcrop, about a mile long and two hundred yards wide. Still farther northwestward the White Limestone is next seen on the south side of Oaktuppah Creek, on Dr. Gilbert's old place and between that place and Mr. Troup Trice's. Then on the north side of Oaktuppah Creek, on Messrs. Seaborn Bonner's and Rigby's lands, Secs. 22, 23, 26, and 27,

[1] In this township the sections are numbered differently from the usual manner.

T. 10 N., R. 4 W., is a narrow tract, about two miles in width north and south; again, still farther westward, on Mr. James Bonner's land, N. W. ¼ of Sec. 15, T. 11 N., R. 4 W., is about a square mile of the White Limestone prairie. Beyond this the prairie belt widens out and merges into the great mass of prairies west of the end of the Hatchetigbee anticline. Returning to our Bladen Springs and Butler road, after crossing the syncline of Claiborne beds which holds the narrow belt of White Limestone, we come upon the Buhrstone rocks again some ten miles south of Butler, and these make the country to within five miles of that place, where they are succeeded by the Hatchetigbee beds, and at Butler by the Wood's Bluff beds.

Third. Along another route, approximately parallel to the two preceding, but in the western part of Choctaw County, we discover that our anticline has sunk beneath the surface, though still impressing itself upon the country by keeping the White Limestone as the surface rock over a distance north and south of more than twenty miles. A very similar state of things may be seen beyond the southeastern end of this fold in Clarke County, as below noted. The following details will serve to make this clear: Three miles south of Pushmataha the Wood's Bluff marl is seen on Rabbit Creek, and a mile or two farther south the first of the Buhrstone, which rock then makes the country southwestward as far as the SE. ¼ of Sec. 25, T. 12 N., R. 5 W., near Mr. Johnson Allen's. In this vicinity *Ostrea sellæformis* beds are found upon many of the high hills which show Buhrstone rocks at their bases. The line between the two formations may therefore be drawn here. Going still southward we find the *Ostrea sellæformis* or Claiborne beds at lower and lower levels, till on Billy's Creek, in Sec. 7, T. 11 N., R. 4 W., they are at the water level, and we get a first rate section extending nearly up to the White Limestone.

Section on Billy's Creek, Choctaw County.

1. Red, white, and yellow, laminated sands, with yellow clay partings.......15 feet.
2. Laminated, gray clays, with bits of leaves and indistinct leaf impressions, 12 to 15 feet.
3. Greenish yellow, calcareous, glauconitic sands; no fossils..................8 feet.
4. White, calcareous sands, with *Ostrea sellæformis*..........................6 feet.
5. Hard, white ledge, with shell casts.......................................1 foot.
6. White, calcareous sands, with *Ostrea sellæformis*, passing below into coarse, yellow sands, and then to gray, calcareous sands, holding a few friable shells; hard ledges traverse these beds near the top; in all..........................12 feet.
7. Highly fossiliferous, gray, calcareous sands, holding *Ostrea sellæformis* (small shells), *Osteodes Wailesii*, *Turbinolia Maclurei*, *Nucula magnifica*, *Pecten Lyelli*, &c. These are alternating streaks of barren sands and fossiliferous sands............20 feet.
8. Gray, laminated clays to base of bluff...................................10 feet.

One of the beds of No. 7 is densely packed with the small form of *Ostrea sellæformis (divaricata)*, and this is the bed which crops out so frequently upon the hills to the northward of this locality. A comparison of the elevations of this bed in different places shows that it dips about 50 feet to the mile. South of Billy's Creek we enter upon the wide belt of prairie land (White Limestone) which extends to the northwestern corner of Washington County four or five miles below Isney. The line between Ranges 4 and 5 W. marks about the western limit of the Hatchetigbee anticline, for east of Push Cush Creek, abcut Sec. 17 or Sec. 18, T. 10 N., R. 4 W., the outcrops of the *Ostrea sellæformis* beds are seen.

The map will show that in the western part of Washington and Choctaw Counties and in adjoining parts of Mississippi the width (north and south) of the White Limestone belt is much greater than elsewhere, except in the eastern part of Clarke County. This is undoubtedly in great measure due to the influence of our Hatchetigbee fold; but there is also a very considerable increase in the thickness of the beds constituting the lower or Jackson division of the White Limestone in the western part of Alabama and in Mississippi, or perhaps it would be more correct to say that there is a very considerable increase in the thickness of the beds of gypseous clay of the formation in these localities. The "prairie" character of the soils of this formation is much more pronounced in Western Alabama and in Mississippi than elsewhere eastward.

Fourth. The limits of the anticline are also well defined along several roads leading out from Bladen Springs.

(*a*) On the road from Bladen Springs to Millry, in Washington County, the Buhrstone and Claiborne formations are crossed, and at a distance of seven or eight miles from the springs appears the first outcrop of White Limestone.

(*b*) On the lower road from the springs to Isney the first outcrop of Buhrstone is about one and a half miles and the last about five miles from the springs. A very conspicuous bed in these Buhrstone rocks is a greensand, several feet in thickness, of very bright, light green color, to be seen on almost every hillside from three to four and a half miles from the springs. In many places the upper part of this bed has been oxidized to deep red sand. From the five mile post west of the springs out to the lower line of Sec. 15, T. 9 N., R. 4 W., we cross diagonally the outcrop of the Claiborne beds, coming into White Limestone at the last named locality, where along a hillside Claiborne beds are seen, with White Limestone overlying them. Thence out to Isney (and beyond to Mississippi) the country is made by the White Limestone. A very good section of the Upper Claiborne beds was obtained in Sec. 13, T. 9 N., R. 4 W.

Section near Jordan's Mill.

1. Yellowish, clayey sands, with some Claiborne fossils in a soft, friable condition; lower part of this bed bluish .... 25–30 feet
2. Projecting ledge of coarse grained greensand, with a large number of badly preserved Claiborne fossils .... 4 feet.
3. Coarse grained greensand, with Claiborne fossils, compact and hard ...... 10 feet.

The upper half of No. 3 is coarser in grain and more fossiliferous than the lower, but the latter contains a number of the smaller forms. A little northwest of this, in Sec. 2, T. 9 N., R. 4 W., at Shoemaker's Mill, this greensand bed is again seen, holding *Crassatella alta.* While in some respects these two outcrops resemble the Claiborne sands (main fossiliferous bed at Claiborne), there are differences observed which lead us to think that their position is below these sands. The limit between Claiborne and White Limestone is seen again about half a mile northeast of Fail's Store.

(*c*) Along the upper road from Isney to Bladen Springs the Buhrstone belt is entered at Powe's Store, about two miles northeast of Silas post office, and from this point on by the Turkey Creek bridge (about Sec. 10, T. 9 N., R. 2 W.) we cross only Buhrstone rocks. No Hatchetigbee beds are observed. From this circumstance it would seem that the outcrop of the last named beds, passing through Bladen Springs, does not extend northwest beyond the line running from Silas to Turkey Creek bridge, these two points being on opposite slopes of the anticline. In the piny woods northeast of Isney there are many outcrops of the *Ostrea sellæformis* beds, betrayed by the appearance of red, limy clay spots in the woods. Thus at Singeley & Peel's store, Sec. 11, T. 10 N., R. 5 W., the immediate surface is sandy and timbered with long leaf pine, but prairie spots (White Limestone) occur on the hillsides in all directions. Two and a half miles due east of this store, in the banks of Push Cush Creek, the *Ostrea sellæformis* beds are seen, as also at Mr. Marion Carroll's (Sec. 21, T. 10 N., R. 4 W.), and in the piny woods southeastward, eastward, and northeastward, for a good many miles.

(*d*) Again, going towards Bladen Landing, Sec. 3, T. 9 N., R. 2 W., the road is over Buhrstone all the way, after leaving the immediate vicinity of the springs.

(*e*) And lastly, going from the springs to Coffeeville, after leaving the Hatchetigbee clays of the springs, the road passes over Buhrstone to the river lowlands; it then follows the river for three miles (no rocks seen) to Coffeeville, where the Claiborne rocks are well exposed. At Coffeeville Landing these rocks have a very strong dip towards the east or northeast, and the White Limestone is encountered within a very short distance of the river bluff eastward. Thus, on the road from Coffeeville to Grove Hill, we see orbitoidal limestone at the level of the small water courses, within five miles of the former place, and at six miles from Coffeeville this rock forms the banks of Satilpa Creek. This marks about the lowest part of the depression, for a mile farther eastward limy clays containing ribs of Zeuglodon are noticed upon a hillside, at some considerable elevation above the level of Satilpa Creek. These lime hills continue thence to within a mile of Grove Hill, where the Tertiary rocks are concealed by the Drift deposits.

From these details it will be seen that this anticline has been tolerably well defined on all sides by our observations, and its representatives on the other map may be taken as fairly correct. In describing the limits of this undulation we have made use of the Buhrstone rocks more than of other formations, for the reason that the Buhrstone, being in general hard and resistant to denudation, may almost always be seen along its line of outcrop. The Claiborne beds (sands and clays), on the other hand, as a rule, are likely to escape detection. It may, however, be of interest to give the following localities of the occurrence of the Claiborne along the two sides of the anticline.

The ferruginous sand bed, with the great mass of the Claiborne shells, we have seen less frequently than the lower or *Ostrea sellæformis* beds.

The former has been observed on the southern side of the anticlinal on Stave Creek, in the SW. ¼ of Sec. 8 and in the SE. ¼ of Sec. 9, T. 7 N., R. 2 E., in Clarke County; on the Tombigbee River, half a mile above Saint Stephens Bluff; also in Sec. 5, T. 8 N., R. 2 W., and in Sec. 29, T. 8 N., R. 2 W., in Washington County. Then in Sec. 13, T. 9 N., R. 4 W., and in Sec. 2, T. 9 N., R. 4 W. On the northern side of the anticline the ferruginous sand bed has not come under observation except on the southern bank of Souilpa Creek, about Sec. 13 or Sec. 25, T. 10 N., R. 3 W.

On the other hand, the lower or *Ostrea sellæformis* beds are to be seen along the whole outline of the anticlinal, and even where the beds do not come to actual outcrop their presence is just as certainly revealed by the occurrence of what are called "piny woods prairies"—that is, red, limy, clay spots in the piny woods. A great proportion of the country underlaid by the *Ostrea sellæformis* beds has a light, sandy soil and is timbered with long leaf pine, and the reaction of the calcareous sands upon the red loams, which occur in these sandy lands, produces the so-called prairie spots. I give a few of the localities of *Ostrea sellæformis* beds around the anticline, beginning at Coffeeville Landing, where there is a fine exposure. Thence northwestward they may be followed up Oaktuppah Creek, on both sides, and forming the bed of the creek in many places, out towards Nicholson's store. Thus, on both sides of Womack Hill, at Barryton Mill; on Surveyor's Creek, Sec. 36, T. 11 N., R. 3 W.; in the banks of Souilpa Creek, at the bridge, about Sec. 13 or Sec. 25, T. 10 N., R. 3 W.; two miles west of Barryton; in the bed of Oaktuppah Creek, about Sec. 28, T. 11 N., R. 3 W.; in Sec. 20, T. 11 N., R. 3 W., on Bogue Loosa; in many places northward as far as Lusk post office, SW. corner of Sec. 9, T. 11 N., R. 3 W.; in Sec. 25, T. 12 N., R. 5 W.; Secs. 6 and 7, T. 11 N., R. 4 W.; in Sec. 15, T. 11 N., R. 4 W.; many places near center and northern part of T. 10 N., R. 4 W.; and thence along the southern border of the anticline, i. e., about Sec. 7 or Sec. 8, T. 8 N., R. 2 W.; then across the river a few miles north of Jackson, &c. Indeed, with a little practice, the *Ostrea sellæformis* beds are about as easily followed as the Buhrstone. In Clarke County, also, as across the river in Choctaw County, in the syncline lying to the northeast of the Hatchetigbee anticlinal, the Claiborne ferruginous sands are in many places not far below the general level of the country, and are exposed in the beds of the water courses. Examples of this are seen in the central part of Sec. 23, T. 9 N., R. 2 E., and in the SE. ¼ of Sec. 18, T. 9 N., R. 3 E.

It will be noticed that along the sides of this anticline, as well as where the Buhrstone first dips below the surface in the northern part of Clarke and Choctaw Counties, the rate of dip is much greater than the average of 30 feet to the mile; for the thickness of the Buhrstone is about three hundred feet, and its outcrop, with a dip of the strata of thirty feet to the mile, would be about ten miles broad, but in the instances cited above this outcrop will not average more than four miles in width. A part of this difference is undoubtedly due to the fact that the Buhrstone usually forms high hills, with a rather steep escarpment looking northward, but a part is also certainly due to the more rapid dip along these lines.

(3) OTHER BUHRSTONE DISPLACEMENTS.

A few words respecting the appearance of the Buhrstone rocks at localities farther south than the anticline just described may not be out of place here. A few miles south of Jackson, on the road to Gainestown, there is a hill which rises to a height of 300 feet above the adjacent water courses. Upon its summit there is a good outcrop of Buhrstone rocks, and in immediate contiguity with it Orbitoidal White Limestone, at the same level. This state of things may be seen also southward and northward of the locality named for at least a mile in each direction, and southward presumably as far as the Lower Salt Works (see below). The locality mentioned is about the corner of the four sections 14, 15, 22, 23, T. 6 N., R. 2 E.; and a mile north of it, in the Etheridge Old Fields, there is another occurrence of Buhrstone and White Limestone in actual contact apparently at the same level, for in both these cases, as we go eastward, we find the White Limestone making the country for many miles. In the same range of hills with the outcrops above mentioned (but eastward of the Buhrstone occurrences), there are places where the ravines have cut down into the *Ostrea sellæformis* beds of the Claiborne. The Tertiary strata lying westward of these localities have generally been removed by denudation, but in one place at least, we find Orbitoidal White Limestone lying to the *west* of the line of contact of Buhrstone and White Limestone, so that to all appearances we have here a narrow belt of Buhrstone (north and south) coming up right in the midst of the White Limestone, and with the latter in visible contact with it on its eastern side. When we go a few miles farther south, to what is called the Central Salt Works, in the northern part of Sec. 34 or the southern part of Sec. 27, T. 6 N., R. 2 E., we find the Orbitoidal White Limestone at the level of the water courses, but a mile east of the Salt Works, up Salt Creek, on ascending a hill we pass over what appear to be the Hatchetigbee strata. Of this I could not be perfectly sure, as no well defined fossils were obtained; but on another branch of the creek, which flows from the north, heading nearly in the localities first mentioned, we find the Buhrstone making the lowermost forty or fifty feet of the hills in both sides of the branch, while the upper strata of the hills were White Limestone, apparently *conformably overlying the Buhrstone*, the strata of the latter at one place, where they were clearly shown in a low bluff, being approximately horizontal. This locality is near the upper edge of Sec. 35 or of Sec. 36 in T. 6 N., R. 2 E., or in the lower part of the section lying next towards the north. At Mr. F. Payne's spring, on the NW. ¼ of NE. ¼ of Sec. 11, T. 5 N., R. 2 E., the Buhrstone is found, while directly west, on the bank of the river, in Secs. 16, 17, 21, 28, and 29 the White Limestone appears. So, also, east of Mr. Payne's house there are lime sinks and outcrops of White Limestone in Secs. 12, 13, 24, &c. Though not actually seen, it would appear that here, also, we have the White Limestone lying directly upon the Buhrstone, the strata falling away rapidly westward so as to bring the former rock down to the river within two or three miles towards the west. A few miles below this, in Secs. 21 and 28, T 5 N., R. 2 E., at the Lower Salt Works, we have the section already given, in which the White Limestone and the Buhrstone are shown in direct contact, the former apparently directly and conformably overlying the latter, just as appears to be the case at Mr. Payne's, at the Central Salt Works, and probably also at the first locality mentioned above (Secs. 14 and 15, T. 6 N., R. 2 E.).

I should be inclined to explain these anomalies on the supposition that a north and south fault has brought the Buhrstone and the White Limestone together, but for the fact that at most of the localities above mentioned the White Limestone may be seen directly, and to all appearance conformably, resting upon the Buhrstone. Whether by a fault or otherwise, all the Claiborne strata are wanting at all these localities, and my observations show also either that there is an anticlinal axis extending from Sec. 28 in T. 5 N., R. 2 E., a little east of north up to Sec. 14, T. 6 N., R. 2 E., which brings the Buhrstone above drainage along this line and for this distance, or that this elevation has been brought about by a fault. There are great difficulties in the way of making satisfactory observations in this part of the State, as thick beds of drift and loam (in some places, as at Mr. Payne's, 75 feet thick) cover the whole face of the country, except where they have been removed by the few streams; but I hope to have this fold or fault fully traced out in another season.

The sulphur spring at Jackson comes apparently through the Buhrstone out of the Hatchetigbee strata, as is the case at Bladen Springs, Tallahatta Springs, the Upper Salt Works, the Lower Salt Works, &c. The Jackson well, however, is in the low grounds of Bassett's Creek, and no Tertiary rocks show in the immediate vicinity, but the Buhrstone and the Hatchetigbee sands appear on a hill at no great distance towards the east.

As before stated, the White Limestone is the country rock through all the lower part of Clarke County, as far south at least as Choctaw Bluff and the Lower Salt Works; but away from the streams these Tertiary beds are hidden by drift, and their presence is revealed only by the numerous lime sinks which are of such frequent occurrence in the piny woods of this section. Below the Lower Salt Works the Tertiary rocks may be continuously followed down to Oven Bluff, a few miles distant, southward of which point they do not appear to come again to the surface. It is probable, however, from the occurrence of lime sinks, that the White Limestone underlies the surface at no great depth for many miles farther in this direction.

The uplift of the Lower Salt Works is felt across to the Alabama River, but not to the same degree as here, for at Gainestown and at Choctaw Bluff the lower measures of the White Limestone are at the water level.

It would not be correct to say that these undulations are not felt at all across the whole of Clarke County; for, although the underlying Claiborne and Buhrstone rocks are not, so far as we now know, lifted much above the general drainage level in the eastern part of the county after having once disappeared beneath the surface, the undulations have still been operative in keeping the White Limestone as the surface rock over an extent, north and south, of 30 miles. This is well illustrated along the meridian of Grove Hill, Clarke County, where we find the White Limestone as surface rock from about five miles north of that town down to Choctaw Bluff, and the thickness of the formation is not much over 300 feet. Moreover, at several localities we find the underlying Claiborne beds at no great depth below the general level of the country. Now, if we travel southward of this last outcrop of the White Limestone at Choctaw Bluff, through Monroe and Escambia Counties, and eastward also, in Covington, Coffee, and Geneva Counties, we find the country generally level piny woods, with a surface mantle of drift, in which, however, the frequent occurrence of depressions caused by lime sinks reveals the fact that the White Limestone is at no great distance from the surface at any place. And, still further, if we pass into Florida we find this rock again at the surface over the greater part of the peninsula, although, as recent discoveries of Mr. L. C. Johnson have shown, covered in many places by later deposits of Miocene age.

The elevation of the Florida peninsula was therefore subsequent to the deposition of the Miocene beds, and the undulations of the Alabama Tertiary may date back to the same epoch. That these disturbances antedate the elevation of the Terrace epoch is shown by the circumstance that the Drift (Champlain) deposits rest upon an eroded surface of the Tertiary (Eocene and Miocene) rocks.

(4) EASTERN EXTENSION OF THE BUHRSTONE.

By referring to the map it will be seen that the northern line of the Buhrstone outcrop, after crossing the Alabama River just below

Johnson's wood yard, turns sharply northeastward to a point nearly east of Bell's Landing and six or seven miles distant therefrom. Then it turns southward six miles, sweeps around eastward and northeastward just south of the lower prong of Flat Creek, running up as far north as Cokerville, near the line between Monroe and Conecuh Counties. Beyond Cokerville it again makes an abrupt turn southeastward and crosses the extreme southwestern corner of Butler County, beyond which point it has not been continuously followed. The two extreme northern points above noted, namely, that east of Bell's Landing and that at Cokerville, are upon dividing ridges, and this northward extension is no doubt in part due to this circumstance, but not altogether. The course of the two branches of Flat Creek has also much to do with this peculiar surface distribution of the strata. These two branches rise near Cokerville, in the northeastern part of Monroe County. The southern branch flows southward and westward, its channel being mostly in the Wood's Bluff strata, while the Hatchetigbee and Buhrstone form an escarpment on the southern border of the creek valley down to its confluence with the northern branch. The latter flows at first northward, then westward, and then southward to the point of confluence above noted. It thus flows out of the Wood's Bluff strata into the Bell's Landing, and even into the Nanafalia beds, coming back in its southward course into Wood's Bluff again, six or eight miles above the confluence.

Northward of the upper branch of Flat Creek we have a wide area of outcrop of the Nanafalia beds in the Grampian Hills of Wilcox County, in some places eight or ten miles in width.

Our observations have not given us the complete explanation of any of these irregularities, and this mere notice of them must suffice for the present.

CRETACEOUS STRATA.

The Rotten Limestone division of the Cretaceous in Alabama consists of about one thousand feet of calcareous strata of very great uniformity in lithologic character throughout, and, similarly, the strata of the Eutaw division are cross bedded sands and laminated clays, possessing no very well marked features in any part; and the same is true of the beds of the Tuscaloosa formation. While, therefore, we might expect to find disturbances in the strata of the Cretaceous group, such disturbances are not easily recognized in the two great subdivisions of this group, by reason of the uniformity in lithological composition above noted. In the upper or Ripley formation of the Cretaceous, on the other hand, alternations of sandy strata with calcareous and fossiliferous strata are easily identified, and disturbances in the stratification do not so easily escape detection.

While our observations in the Cretaceous territory have not been so extended as in the Tertiary, we are yet able to note a few instances of well marked irregularities in the Ripley formation of this group.

(1) CANTON LANDING, ALABAMA RIVER.

In the river bluff at this locality we have the following section of the Ripley strata:

Section at Canton Landing, Alabama River.

1. Surface beds covering first terrace of the river .... undetermined.
2. Light gray, calcareous sands, with an indurated ledge of nearly pure sandstone at base .... 6 feet.
3. Bluish gray, sandy clays, passing downwards gradually into a more sandy bed containing numerous phosphatic casts and nodules (sandy bed 3 feet thick) .. 8 feet.
4. Bluish, argillaceous, calcareous beds, holding great numbers of *Exogyra costata*, *Gryphæa*, and casts .... 3 feet.
5. Bluish, calcareous sands containing many fossils, chief among which a *Spondylus*, a *Nautilus*, and turreted shells, to water level .... 3 feet.

In one place here a block about 50 yards long of the face of the bluff has been broken from the rest of the strata and settled down some six to eight feet, bringing the base of bed No. 2 of the section down to the top of No. 4 of the undisturbed strata.

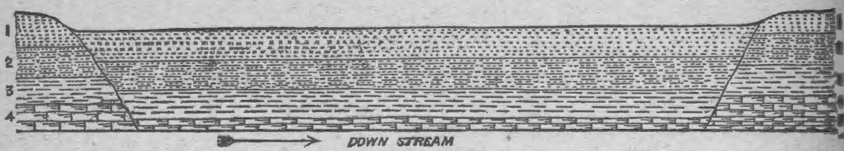


FIG. 1. Displacement at Canton Landing.

The figure gives an idea of this, and it is to be remarked further that the beds of the main bluff at the left of the break are lower than those at the right (with reference to the water level) by two or three feet.

(2) PRAIRIE BLUFF, ALABAMA RIVER.

At this place, as noted above, we have at the top of the bluff some 15 or 20 feet of fossiliferous, calcareous beds, including part at least of those just given as occurring at Canton Landing, and below these to the river level some 60 feet of sandy strata traversed by bands of indurated sands containing numbers of large shells of Gryphæa and Exogyra. These sandy strata have a very rapid dip down stream (southward) of some 300 to 350 feet to the mile; while the calcareous beds at the top of the bluff, according to the recent observations of Mr. Langdon, show a much less decided dip, it being only about 30 or 40 feet to the mile. This may be and probably is due to the cross bedding on a large scale of the sandy strata.

A mile or two above Prairie Bluff we have another exposure of these sandy strata, with similar rapid dip down stream. This dip, if uniformly continued down to Prairie Bluff, would bring these beds 300 to 400 feet below the visible portion of that bluff, while in all probability

1. Second bottom deposits, which overlie the black, shaly clays forming No. 1 of the section on p. 79.

(Black, shaly clays, No. 1 of the section on p. 79, are the uppermost beds in this diagram.) 2. Ledge of Gryphæa shells, No. 3 of the section on page 79. 3. Irregular pockets of cross-bedded sandstone embedded in the limestone No. 4 of the section on page 79. (No. 2 of the section on page 79 is included between 1 and 2 of this diagram.)

2. Thin ledge of Gryphæa shells, No. 3 of the section on page 79. 3. Irregular pockets of cross-bedded sandstones embedded in the limestone No. 4 of the section on page 79. (Several faults are shown in this part of the river bank.)

2. Ledge of Gryphæa shells, No. 3 of the section on page 79. 3. Irregular pockets of cross-bedded sandstone embedded in the limestone No. 4 of the section on page 79.

DIAGRAM SHOWING EXPOSURE OF RIPLEY STRATA ON RIGHT BANK OF TOMBIGBEE RIVER, FROM MOSCOW LANDING (MARKED BY THE HOUSE) DOWN THE RIVER.

the strata of the two bluffs are, in part at least, the same, and it is probable that between the two places these strata undulate very decidedly or are perhaps faulted.

(3) MOSCOW, TOMBIGBEE RIVER.

Some of the calcareous beds of the Ripley formation are exposed along the right bank of the river from Moscow a mile or two down stream. In these bluffs, which are continuous, about fifty feet in all of these strata may be seen, and there is no difficulty in following any particular stratum to its disappearance below the water level. The strata here exposed are the following:

Section near Moscow, Tombigbee River.

1. Black, shaly clay like that of Black Bluff, supposed to be Tertiary, but devoid of fossils .... 10 to 15 feet.
2. Dark blue, argillaceous limestone, with thin, projecting ledges of harder material. One of these ledges, about 8 feet below the black clay, is very persistent, and easily followed from Moscow down to the cut off just above the mouth of Sucarnochee Creek .... 20 to 30 feet.
3. Thin ledge of shells of a small *Gryphæa* .... 1 to 1½ feet.
4. Hard, argillaceous, white limestone, resembling the Rotten Limestone, containing many Cretaceous shells, as *Exogyra costata*, *Gryphæa mutabilis*, &c.; especially in the upper part, which is indurated .... 25 feet.

Near the top of stratum No. 4 there are at several places along the river hard, sandy ledges of very irregular shape, and discontinuous. These sandstones contain comminuted shells embedded in a sandy matrix. The thin ledge of Gryphæa shells (No. 3) and an indurated ledge near the top of No. 2 are easily recognized, and they serve to identify the other beds.

In going from Moscow down to the cut off we see that the above described strata are not only undulating but at seven or eight places distinctly faulted.

The accompanying diagram of the right bank of the river, carefully sketched from nature, shows very clearly the character of these disturbances and renders any further description in words superfluous (Plate X).

VI. RÉSUMÉ.

THE FORMATIONS.

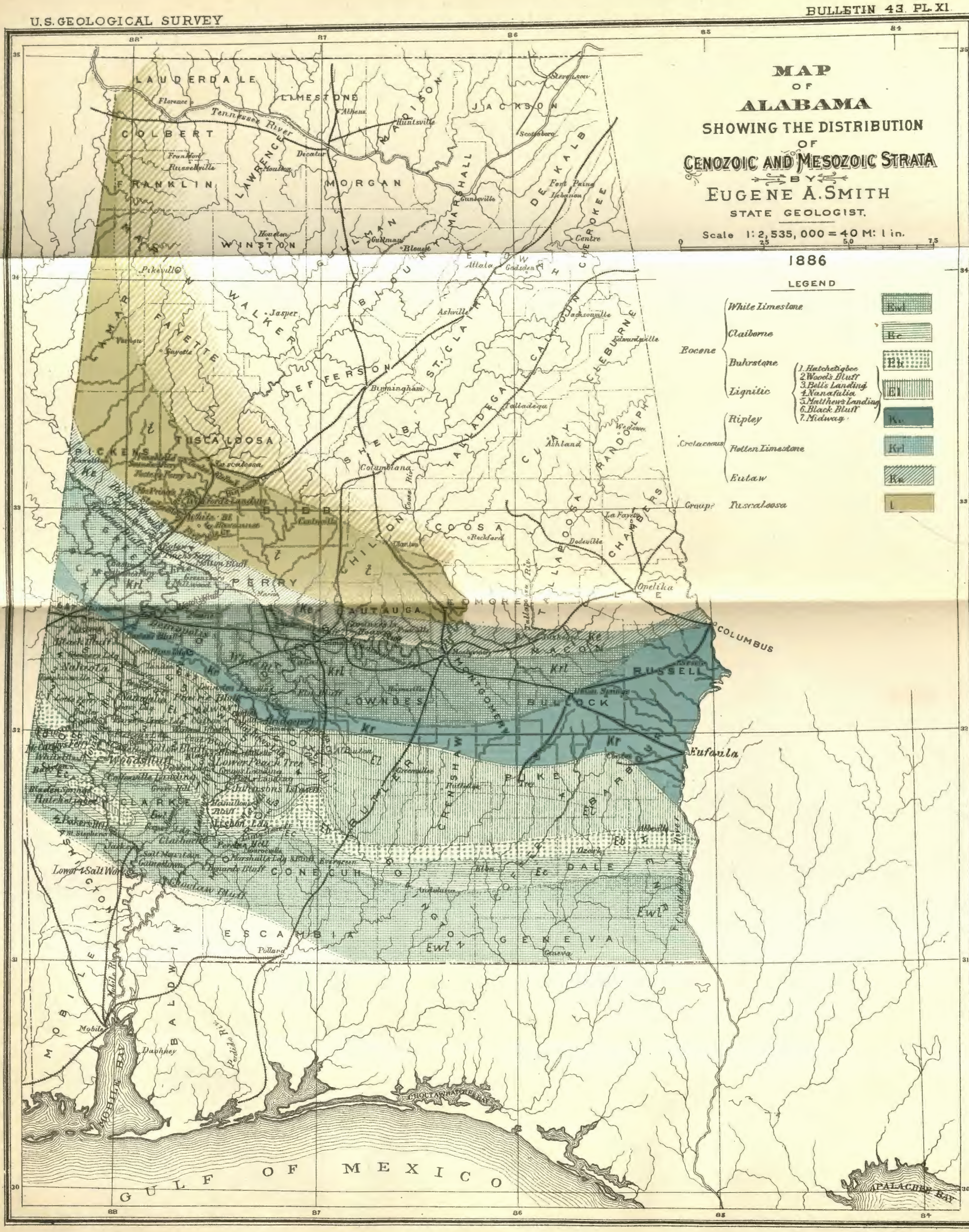
The general section forming Plate XXI is so arranged as to exhibit in the two inner columns, by conventions and descriptive text, the structure and character of the formations exposed along the rivers traversed and our conceptions of their relations. The portions of the sections in which the conventions are introduced are constructed from observations recorded in the foregoing pages and the portions left blank represent those parts of our ideal section in which exposures do not occur along either river. In the two outer columns are exhibited in similar manner those portions of the formations not actually seen along either river, which are either exposed in the immediate vicinity of the rivers so clearly as to leave no doubt as to their stratigraphic relations or else disclosed by artesian borings. These two columns, therefore, serve either to fill out the missing parts of the river sections or to confirm the measurements made elsewhere.

By reference to the text and to the general section it will be seen that in the Tertiary group we have been able to fill up the blanks thus occurring along the rivers by direct measurement of the exposures seen in the vicinity of the rivers, except in two places, viz, just below the Bell's Landing section and below the Coal Bluff section of the Lignitic. The stratigraphic column of the Tertiary formation, therefore, with the two exceptions noted, is constructed from actual measurements. From the known thickness of the several divisions which we have made in the Tertiary and their extent upon the surface, we find, from careful observations made at many points, that the average general dip of the Tertiary strata is about 30 feet to the mile towards the southwest. There are, however, undulations and variations in the dip, culminating in the vicinity of the Tombigbee River, where the disturbances are more conspicuous than anywhere else in the post-Appalachian clastics of the Atlantic and Gulf slopes, so far as known. These have been described in the preceding pages.

Similarly in the upper part of the Cretaceous group the stratigraphic column has been constructed in great part from actual measurements; but in the lower part of the known Cretaceous and in the whole of the Tuscaloosa formation, where our observations have been less numerous and satisfactory, we have assumed a uniform southwesterly dip of 40 feet to the mile, and the thicknesses thus assigned to the imperfectly exposed beds are only approximations, though, as we think, close approximations. In the artesian boring at Livingston, which is upon the extreme southern border of the Rotten Limestone, the thickness of this rock actually penetrated is 930 feet, and as the Rotten Limestone forms the surface between Livingston and Eutaw, a distance across the strike of 24 miles, the average dip is seen to be about 40 feet to the mile.

Some of the leading structural features of the formations described may be recapitulated.

The newest of the formations exposed along our route is the White Limestone. It consists chiefly of regularly bedded, impure limestone, with intercalated layers of marl, calcareous clay and sand, and some ledges of pure limestone. Its upper portion is perceptibly more calcareous than the lower and contains a notably greater proportion of deep sea fossils; but neither the lithologic nor the paleontologic features are sufficiently distinct to warrant division of the formation. Its position and its structure alike indicate that it was laid down in a deep and probably deepening sea.


MAP
OF
ALABAMA
SHOWING THE DISTRIBUTION
OF
CENOZOIC AND MESOZOIC STRATA
BY
EUGENE A. SMITH
STATE GEOLOGIST.
Scale 1: 2,535,000 = 40 M: 1 in.
1886
LEGEND
Eocene
White Limestone
Claiborne
Buhrstone
Lignitic
1. Hatchetigbee
2. Wood's Bluff
3. Bell's Landing
4. Nanafalia
5. Matthews Landing
6. Black Bluff
7. Midway
Cretaceous
Ripley
Rotten Limestone
Eutaw
Group? Tuscaloosa
Ewl
Ec
Eb
El
Kr
Krl
Ke
t
GULF OF MEXICO
MOBILE BAY
APALACHEE BAY
COLUMBUS

The Claiborne formation is made up of tolerably uniformly bedded, calcareous, and generally glauconitic sands and clays, containing rather shallow water, but not littoral, fossils mingled with deep sea organisms. There is no conformity or clearly marked line of demarkation between the Jackson beds of the White Limestone and the upper calcareous beds of the Claiborne, the one grading imperceptibly into the other, both lithologically and paleontologically.

The Buhrstone deposits are sands and clays variously interstratified, generally lithified by silicious cement. Some of the clays are remarkably pure and fine grained. The fauna is meager, but of facies identical with that of the Claiborne.

The Lignitic formation comprises three well marked divisions defined by color, which is here an index of constitution. The upper one-fourth consists of irregularly bedded, dark, silicious, and lignitiferous clays and heterogeneous sands, approaching the basal portion of the Buhrstone formation in composition and structure, interstratified with discontinuous beds of lignite and continuous layers of clay and sand containing marine fossils. The medial three-fifths of the formation is made up of rather more regularly stratified clays and sands of light color, frequently cross bedded, containing occasional beds of lignite and of marine sands yielding littoral fossils, one of which (the *Gryphœa thirsœ* bed) is 50 to 60 feet in thickness. The basal deposits are irregularly bedded, dark, or even black, calcareous, shaly or slaty clays, with few fossils or definite beds of lignite, though considerable quantities of carbonaceous matter are disseminated throughout its mass.

At the base of the Lignitic there is a rapid change in the character of both rocks and fossils, the lowermost 15 or 20 feet of the formation being limestone, at first argillaceous, then quite pure, and even crystalline. This crystalline limestone rests with apparent conformity upon the yellow sands which make the summit of the Cretaceous group.

The materials of the Ripley formation are generally fine and uniformly bedded, particularly toward the summit, are predominantly arenaceous at top and bottom, though notably calcareous, particularly in the middle layers, and are often richly phosphatic. The formation is characterized by littoral or offshore, but not strictly pelagic, fossils.

The Rotten Limestone consists of uniformly bedded and tolerably homogeneous, argillaceous, or rarely pure limestones and clay marls, with occasional intercalations of clay and sand, sometimes glauconitic. Its abundant fauna is pelagic rather than littoral.

The transition beds between this and the Eutaw formation—the Tombigbee sand of Hilgard—are predominantly arenaceous and glauconitic, and speak of shallower waters than those of the Rotten Limestone.

The Eutaw deposits, like those of the Ripley, are usually fine and uniformly bedded, though they are more arenaceous than those of the latter formation. They consist of alternations of sand and clay, the former often cross bedded and glauconitic, and the latter lignitiferous, together with occasional lignitized tree trunks and intercalated beds of lignitic matter or pebbles. The rare fossils have a littoral aspect.

No unconformity has been found between the Eutaw and Tuscaloosa formations, and the similarity in lithologic character and attitude of the two is so close that search for discordance is unpromising.

The Tuscaloosa formation consists of a great series of irregularly or obscurely bedded, quartzitic and micaceous sands, often cross stratified; heterogeneous clays, sometimes carbonaceous or lignitiferous; lenticular pebble beds (the pebbles very commonly of chert); and discontinuous lignitic layers. With the exception of the lignite and leaf impressions, it has yielded no fossils.

The coarse sands and laminated clays forming the base of the Tuscaloosa formation repose unconformably upon the eroded surface of the Carboniferous and other Paleozoic rocks.

THE GENESIS OF THE FORMATIONS.

A preliminary report on a limited region is scarcely the place for recording a chapter in the evolution of the continent; but we are convinced that, by reason of the poverty in organic remains of many of the formations, the paucity of our knowledge of the geographic distribution and local variation of their faunas and floras, and the unity and simplicity of the terrestrial oscillations to which they are referable, the Cenozoic and Mesozoic formations of the Gulf and Atlantic slopes must eventually be correlated physically rather than paleontologically; and we at the same time emphasize this conviction and contribute toward the chief end of geologic science—the co-ordination of terrestrial phenomena—by setting forth in terms of written language what we conceive to be the history recorded in the Cenozoic and Mesozoic rocks of Alabama.

At an undetermined epoch in the Mesozoic, the southern extremity of the Appalachians, together with the Piedmont region on the east and the Cumberland Plateau on the west, was submerged; and the uneven surface sculptured by subaërial erosion formed an irregular shore line diversified by a multitude of estuaries and a highly inclined and unequal sea bottom. Within the estuaries and upon the uneven sea bottom the strong currents, high tides, and violent waves of a deep sea coast washed here and there, assorted rudely, and finally deposited the coarse detritus brought down by numerous streams of high declivity—the upper reaches of river courses shortened by submergence and steepened by tilting; the strong currents, the constant shifting of the littoral deposits, and the variable salinity of the estuarine and shoreward waters (depending upon the seasonal and non-periodic variability in stage of the affluents) were inimical to organic existence; but leaves, logs, and other vegetal matters were occasionally swept into the sea by the rivers. The downward movement during this epoch was interrupted and, about the middle of the epoch, perhaps reversed; but in general it went on progressively. With continued deposition a submarine terrace analogous to those now fringing the Atlantic and Gulf coasts was apparently developed; and, with the growth of the terrace and consequent shallowing of the offshore waters, there was evidently a diminution in strength of currents and violence of waves, accompanied by a diminution in heterogeneity and coarseness of sediments. The deposits produced by these agencies are those of the Tuscaloosa formation.

During the epoch immediately succeeding that of the deposition of the Tuscaloosa formation, so far as our present knowledge indicates, there occurred a diminution in the rate or perhaps a cessation of the downward continental movement; but there were continued growth of the submarine terrace, shoaling of the sea by reason of sedimentation, and some recession of the shore line. The shoal water deposits of this epoch constitute the Eutaw formation.

The Rotten Limestone epoch was apparently inaugurated by a comparatively sudden renewal of the continental depression and rapid deepening of the sea. The sands of the Tombigbee were distributed by the advancing waves of the encroaching sea, and in the deep waters of the succeeding episode the abundantly fossiliferous limestones and marls of the later Cretaceous were laid down. During this epoch the waves of the Cretaceous probably lapped upon the Appalachians higher and farther inland than the Tuscaloosa shore line.

The succeeding epoch was marked by a reversal in terrestrial movement, progressively increasing coarseness and heterogeneity of sediments, rapid retreat of the shore line down the gentle slope of the adolescent submarine terrace, diminution in salinity commensurate with the relatively great (though absolutely constant) influx of fresh waters, some commingling of terrestrial plant débris with the sediments, and diminution in abundance of marine organisms. The deposits of the epoch constitute the Ripley formation and indefinitely mark the closing stages of the Cretaceous period.

The Tertiary was introduced by a continuation of the Ripley elevation sufficient to produce shoaling of the ocean over the then broad submarine terrace, diminished salinity of the littoral waters and consequent destruction of marine organisms, and extension of the terrestrial flora and commingling of its remains with the littoral deposits. There is thus a paleontologic but not (in the portions of the formations that have resisted erosion) a physical break in the sequence of events and in the continuity of strata. The altitude of the land with respect to the sea was generally persistent throughout the Lignitic epoch, but depression apparently went on pari passu with sedimentation, and there were occasional oscillations and consequent incursions of the sea upon the land—notably those represented by the Wood's Bluff and *Gryphæa thirsæ* beds—and excursions of the terrestrial flora upon the coastal marshes.

The Lignitic formation is the analogue of the Tuscaloosa; but by reason of the less acclivity and the less inequality of the sea bottom and the greater regularity of the shores the waves and currents were less violent, and in consequence the deposits are more homogeneous. The approximate horizontality and the shallowness of the sea bottom are attested by the great geographic extent of beds referable to slight changes in depth of the littoral waters.

From the initiation of the Tuscaloosa epoch to the close of the Lignitic, the offshore sediments appear to have been pushed progressively farther and farther into the sea, and the depression accompanying the sedimentation appears to have been uniform throughout the area over which the deposits are now exposed; but the Lignitic epoch was apparently terminated by a depression (perhaps due to its own weight) of the margin of the subaqueous shelf thus formed, and a consequent increase in depth of the off shore waters and in violence of waves and currents. These conditions induced increased heterogeneity and coarseness of deposits, the invasion of a deep sea fauna, and the entombment of its remains in littoral deposits. The formation thus developed we denominate the Buhrstone. The shore probably retreated rapidly and far inland during the Buhrstone epoch, particularly in its earlier episodes.

The Buhrstone epoch waned with the cessation of the seaward tilting; and, with the consequent reconstruction of a submarine terrace and some concomitant depression, there was introduced a slight physical change in the character of the deposits, without paleontologic break, marking the introduction of the Claiborne. Throughout, the Claiborne epoch depression proceeded somewhat more rapidly than sedimentation, and with increasing depth of waters went increasing homogeneity and fineness of deposits.

The continuation of the Claiborne depression was accompanied by gradual modification in physical character of the deposits and by differentiation of fauna, culminating in the latter part of the White Limestone epoch, when the Tertiary sea reached a depth approaching and perhaps equaling the maximum attained during the Cretaceous.

During the Claiborne and the White Limestone epochs the distribution of sediments was apparently such as again to bring the sea bottom to approximate horizontality; and, with what appears to have been a sudden re-elevation of the land, conditions similar to those under which the Lignitic formation was laid down were once more introduced, and the shoal water strata of the Grand Gulf formation—the homologue of the Lignitic—were laid down upon the seaward margin of the White Limestone.

Thus, our preliminary observations suggest the movements and in some cases the positions of the Cenozoic and Mesozoic shore lines, and enable us to say that the breaks in stratigraphic and paleontologic continuity in these formations are apparent rather than real and are due to simple and readily determinate continental movements.

PLATES XII-XXI,

WITH EXPLANATIONS.

PLATE XII.

SECTIONS OF THE WHITE LIMESTONE ALONG THE TOMBIGBEE AND ALABAMA RIVERS, IN PART SHOWING THE RELATIVE POSITIONS OF THE WHITE LIMESTONE AND THE CLAIBORNE BEDS.

FIG. 1. *Section of Salt Mountain, Clarke County.*

1. White Limestone, forming Salt Mountain. This limestone consists in great measure of masses of partially silicified corals. In the lower strata compact, crystalline limestone occurs, which holds plates and spines of echinoderms....150 feet.
2. Orbitoidal White Limestone quarried for building purposes ....20 feet.

FIG. 2. *Saint Stephens Bluff, Tombigbee River.*

1. Soft White Limestone, with *Orbitoides Mantelli.* The upper half contains this fossil in great abundance, the lower part more sparingly. The lithological character of the whole 70 feet is quite uniform. The top of Saint Stephens Bluff is here represented as equivalent to the top of the orbitoidal limestone at Salt Mountain, giving the *minimum* thickness of this rock. There may be, however, a greater thickness of this rock than here shown ....70 feet.
2. Indurated bed of *Spondylus dumosus*..3 feet.
3. Light yellowish white marl or argillaceous limestone, containing nodules of phosphate of lime. The marl itself is strongly phosphatic ....27 feet.

FIG. 3. *Section at Baker's Hill, continuation of Saint Stephens Bluff, showing relative positions of the White Limestone and the Claiborne sands, Tombigbee River.*

1. Orbitoidal White Limestone forming summit of hill, passing into the argillaceous limestone below (line between the two here rather arbitrarily drawn)....25 feet.
2. Argillaceous, glauconitic limestone, with *Pecten perplanus*, *Pecten Poulsoni*, &c. This is the same rock as that at base of Saint Stephens Bluff, half a mile distant and in plain sight. The strata are covered at intervals by débris.
3. Bed with *Scutella Lyelli*, 1 foot seen; at other points........................3 feet.
4. Coarse, ferruginous sands passing downwards to reddish sand, holding the usual Claiborne fossils of unmistakable character..........................15 to 18 feet.
5. Bluish green, glauconitic, and clayey sands, containing the *Flabellum* found at Coffeeville ....8 to 10 feet.

FIG. 4. *Strata exposed in continuous bluffs between Marshall's Landing and Rattlesnake Bluff, just below Claiborne, showing relative positions of the White Limestone and the Claiborne sands, Alabama River.*

1. Orbitoidal White Limestone of the usual character ....10 feet.
2. White Limestone, containing great numbers of *Scutella Lyelli* and other echinoderms ....10 feet.
3. Calcareous clay in two beds of five feet each, separated by three feet of soft, earthy White Limestone. Below this, a ledge of hard limestone three feet and eight feet of blue clay with fucoids, becoming more calcareous below, in all.. about 24 feet.

4. Ledge of hard, white limestone, followed by twenty feet or more of argillaceous soft, white limestone, with thin projecting ledges of purer limestone at intervals. Resembles the Rotten Limestone of Cretaceous formation ....about 25 feet.
5. Bed of *Scutella Lyelli*, in three layers, the middle one ferruginous...........3 feet.
6. Coarse, ferruginous sand, calcareous below, hard ledge at bottom ....6 feet.
7. Claiborne ferruginous, fossiliferous sands, the counterpart of those at Claiborne Bluff ....10 to 12 feet.
8. Calcareous, sandy clay, with hard ledge in middle ....6 feet.
9. Sandy, clay marl, with *Ostrea sellæformis;* four or five hard ledges passing into greensand below..........12 feet.

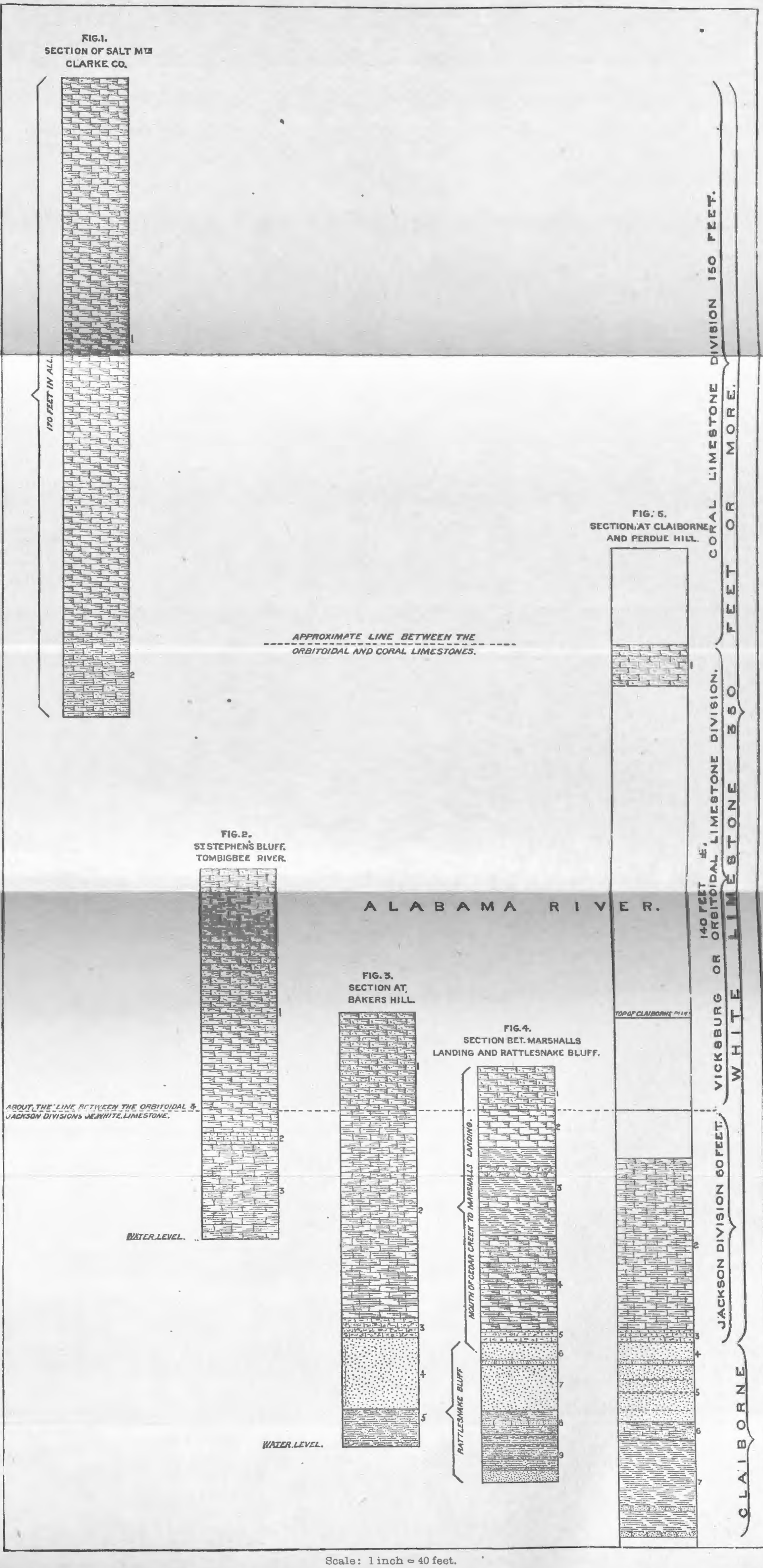
FIG. 5. *Section of upper part of bluff at Claiborne and of part of hill back of bluff, along the road to Perdue Hill, Alabama River.*

Hill back of river bluff.

1. White Limestone filled with *Orbitoides Mantelli*, occurring on road to Perdue Hill, 100 feet or more above top of bluff at Claiborne Landing. Tertiary strata covered by Drift along road leading from Perdue Hill up to Claiborne..90 to 100 feet. Tertiary strata covered by Drift, at top of river bluff ....38 to 40 feet.

Upper part of bluff.

2. White or bright colored, argillaceous limestone with glauconite grains.....45 feet.
3. Indurated ledge of *Scutella Lyelli*..........3 feet.
4. Coarse, ferruginous sand, calcareous below, indurated at base ....6 feet.
5. Claiborne fossiliferous sands, ferruginous. Lignitic in places above..15 to 17 feet.
6. Bluish green, glauconitic, sandy marl, with *Ostrea sellæformis*, part indurated.4 feet.
7. Calcareous, bluish gray clay, few badly preserved fossils, passing below into a greenish, glauconitic marl containing great numbers of young *Ostrea sellæformis* and a few *Pectens*, together about 18 feet; below this, light gray, calcareous clay, similar to top of preceding hard, sandy ledge at top and bottom, 7 feet; in all..........25 feet.



Scale: 1 inch = 40 feet.

SECTIONS OF THE WHITE LIMESTONE ON ALABAMA AND TOMBIGBEE RIVERS

PLATE XIII.

ILLUSTRATING THE CLAIBORNE STRATA AS EXPOSED ALONG THE ALABAMA AND TOMBIGBEE RIVERS.

FIG. 1. *Section by C. S. Hale.*

No. 8. White Limestone, thickness not given by Hale.

No. 7. Yellow, quartzose sand, highly fossiliferous; seam of earthy lignite near the middle........15 feet.

No. 6. Clay bed, with shells of full grown *Ostrea sellæformis*........20 feet.

No. 5. Marly, arenaceous beds, with same shells as are common in the other beds; thickness not given by Hale.

No. 4. Argillaceous, muddy deposits. Fossils mostly oyster, except *Venericardia planicosta*, *Arca*, and *Turritella*; occurs also at Coffeeville........15 to 20 feet.

No. 3. Only a few feet at Claiborne; greensand running gradually into No. 4.

FIG. 2. *Section by Professor Tuomey.*

g. Red loam, sand, and pebbles........30 feet.

f. White and mottled clay........8 feet.

e. Limestone, with a small percentage of greensand........54 feet.

d. Sandy, fossiliferous bed........15 feet.

c. Whitish limestone, with bed on top containing *Ostrea sellæformis* and *Scutella Lyelli*. This bed passes below into a bluish marl with shells........62 feet.

b. Bed of clay, with limestone seam on top. This bed is more calcareous below and contains fossils that, as a group, are peculiar........15 to 18 feet.

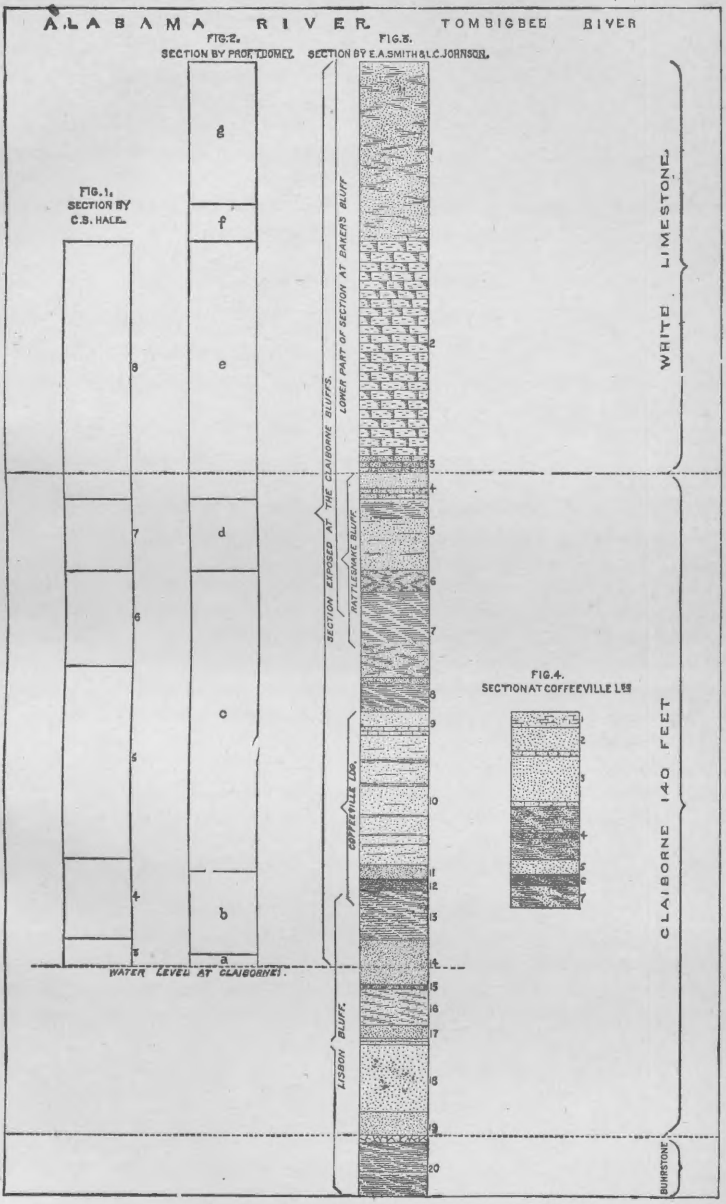
FIG. 3. *Section by E. A. Smith and L. C. Johnson.*

1. Red loam, sand, and pebbles........35 to 40 feet.
2. Argillaceous limestone, with greensand grains........45 feet.
3. Indurated ledge, with *Scutella Lyelli*........3 feet.
4. Coarse, ferruginous sand, calcareous below; indurated ledge at base........6 feet.
5. Claiborne fossiliferous sands; ferruginous sands, with shells; laminated lignitic clays, with leaf impressions, and thin seams of lignite in places in upper part........15 to 17 feet.
6. Bluish green, glauconitic sandy marl, containing *Ostrea sellæformis*, in part indurated........3 to 4 feet.
7. Calcareous, bluish gray clay, with a few badly preserved fossils, passing downward into a greenish, glauconitic, sandy marl, containing great numbers of young shells of *Ostrea sellæformis* and a few *Pectens*, the two together, clay and sand........about 18 feet.
8. Light gray, calcareous clay, similar to the preceding, with hard, sandy ledges at top and bottom, in all........about 7 feet.
9. Light yellowish gray, calcareous sands, with *Pectens* and *Ostrea sellæformis*, the lower half indurated, containing casts of univalve shells........about 5 feet.

10. Light yellowish gray, calcareous sands, with thin beds of more clayey texture and with five or six hard, sandy ledges at intervals; the sand is, in places, loose and crumbling, and quite fossiliferous, with *Ostrea sellæformis*, *Pecten Deshayesi*, fragment of *Scutella Lyelli*, &c., lower 8 feet a bluish, clayey sand . about 27 feet.
11. Bed of greensand, with perfect shells and fragments of *Ostrea sellæformis*, &c. .... about 3 feet.
12. Dark blue, nearly black, sandy clay .... 2 feet.
13. Bluish green, clayey sands, few fossils above, but highly fossiliferous below and rather more clayey, *Venericardia planicosta*, *Nucula magnifica*, *Ostrea sellæformis*, *Arca rhombodella*, *Voluta Sayana*, *Turritella Mortoni*, *T. bellifera*, &c .... 10 feet.
14. Dark grayish blue greensand, peculiar small form of *Venericardia planicosta*, large *Turritella Mortoni*, &c., 6 feet at Claiborne, but 10 feet at Lisbon.
15. Hard, sandy ledge .... 8 inches.
16. Calcareous, clayey sands, lighter yellowish to white color .... 8 feet.
17. Coarse, ferruginous sands, with numerous fossils .... 3 feet.
18. Light yellow sands, capped with a hard ledge, forming perpendicular bluff. 15 feet.
19. Blue, glauconitic sands, probably a modification of 18 .... 5 feet.
20. Bluish black clay; top of Buhrstone contains curious concretions of sandy clay, like interlacing roots.

FIG. 4. *Section at Coffeeville Landing, Tombigbee River.*

1. Light yellowish sands, partly indurated, with *Ostrea sellæformis*, &c .... 3 feet.
2. Loose, yellowish, calcareous sands, with *Ostrea sellæformis*. Indurated sand ledge at base .... 6 feet.
3. Loose, yellowish gray, calcareous sands, highly fossiliferous below, *Ostrea sellæformis* the chief form, separated from next by hard, sandy ledge .... 10 feet.
4. Bluish, clayey sand, with *Ostrea sellæformis* and *Flabellum*, in two parts, separated by hard ledge: upper part, 8 feet; lower, 3 feet, in all .... 12 feet.
5. Glauconitic sands, filled with comminuted and perfect shells of *Ostrea sellæformis*, &c. .... 3 feet.
6. Dark bluish black, non-fossiliferous, sandy clays .... 2 feet.
7. Dark bluish green, clayey sand to water level .... 5 feet.



Scale: 1 inch = 40 feet.

SECTIONS OF THE CLAIBORNE STRATA ALABAMA AND TOMBIGBEE RIVERS

PLATE XIV.

SECTIONS OF THE BUHRSTONE STRATA WITH THE ADJACENT STRATA OF THE CLAIBORNE AND LIGNITIC.

FIG. 1. *Section at Lisbon, Alabama River.*

1. Light yellow sands, with glauconite, capped with hard ledge, lower 5 feet of bluish color, base of Claiborne rocks.......20 feet.
2. Bluish black jointed clay, sandy concretions in upper part.......15 feet.

FIG. 2. *Section at Hamilton's Landing, Alabama River.*

1. Light gray, indurated clays and aluminous sandstones, with one or two indurated ledges, forming the whole of the bluff at Hamilton's Landing.......75 feet.

FIG. 3. *Section exposed along road leading up hill west of McCarthy's Ferry, Tombigbee River.*

1. Top of hill west of McCarthy's Ferry, in Choctaw County. On the road down to the ferry 250 to 270 feet of Buhrstone rocks are passed over. These consist of indurated clays, claystones, and aluminous sandstones; the relative positions and order of succession of the different beds not intended to be represented in figure. These rocks appear at the surface at short intervals all the way..exposed 270 feet.
2. Ledge of silicious sandstone or quartzite, interstratified with indurated clays.
3. Laminated clays, reddish and yellowish, just below Buhrstone rocks on road down the hill; strata exposed just back of bluff of river.
4. Sandy clays &c. (Continuation, see Fig. 3, Plate XV.)

FIG. 4. *Section of upper part of White Bluff, below Wood's Bluff, Tombigbee River.*

1 Aluminous sandstones and indurated clays with jointed structure, forming a clear perpendicular bluff.......115 feet.
2. Grayish, sandy clays, with a layer 18 inches thick at base, containing lignitized stems and twigs.......20 feet.
3. Sandy clays, lignitic layer at base.......5 feet.

FIG. 5. *Section of the upper part of Hatchetigbee Bluff, Tombigbee River.*

1. Light colored, aluminous sandstone and indurated clays.......20 to 30 feet.
2. Sandy clays, brown, yellow, and red, interstratified, bluish when wet, but lighter when dry.......20 feet.
3. Heavy bedded, brownish clays, darker than the preceding.......10 feet.

PLATE XV.

ILLUSTRATING THE HATCHETIGBEE SECTION OF THE LIGNITIC, BUT INCLUDING ALSO A PORTION OF THE LOWER PART OF THE BUHRSTONE AND THE UPPER PART OF THE WOOD'S BLUFF SECTION.

FIG. 1. *Section of White Bluff, Davis's Bluff, and Wood's Bluff, Tombigbee River.*

1. Buhrstone rocks, chiefly aluminous sandstones and indurated clays, with jointed structure and prevailing light gray colors, forming a perpendicular cliff..115 feet.
2. Grayish, sandy clays, with a layer 18 inches thick at base, containing lignitic stems and twigs........20 feet.
3. Sandy clays, with lignitic layer at base........5 feet.
4. Strata obscured by landslides........65 feet.
5. Dark gray, sandy clays, striped with brownish purple bands of clay containing very few fossils, except in a thin band of marl 12 feet above the water and one 24 feet above the water, all exposed in Davis's Bluff........70 feet.
6. Dark gray to brown, sandy clays, between Wood's Bluff and Davis's Bluff..10 feet.
7. Bluish, sandy, fossiliferous clay, red on surface, hard ledge at top........3 feet.
8. Bluish, sandy clay, like No. 7, but not fossiliferous, passing into greensand below........7 feet.
9. Fossiliferous, clayey greensand........3 feet.
10. Greensand marl, with stratum of ponderous oyster shells, highly fossiliferous; tends to form rounded bowlders........10 feet.
11. Fossiliferous greensand, loose and easily washed out, forming caves under the bowlders........8 feet.
12. Thin band of lignite over greenish, non-fossiliferous, clayey sands........5 feet.
13. Laminated, gray, sandy clays........3 to 4 feet.
14. Lignite........8 feet or more.

FIG. 2. *Section at Hatchetigbee Bluff, Tombigbee River.*

1. Drift and surface materials, light colored, aluminous sandstones and indurated clays, Buhrstone rocks........20 to 30 feet.
2. Sandy clays of brown, yellow, and red colors, interstratified, blue when moist, lighter color when dry........15 to 20 feet.
3. Heavy bedded, brownish clays of darker color than No. 2........10 feet.
4. Yellowish, glauconitic marl........3 feet.
5. Purplish brown, sandy clays, with band of hard, dark colored clays in middle, projecting........15 feet.
6. Yellowish gray sands, striped with brown clays, forming bowlders at intervals........6 feet.
7. Blue clay marl, sandy, many new forms........5 feet.
8. Grayish sands striped with brown clay bands, bowlders........4 feet.
9. Heavy bedded, gray, sandy clays, with brown clay stripes, indurated at base..8 feet.
10. Reddish, fossiliferous sand, *Venericardia planicosta* abundant........5 feet.
11. Dark gray to brown, sandy clays, to water's edge........15 feet.

FIG. 3. *Section at McCarthy's Ferry, Tombigbee River.*

1. Buhrstone rocks exposed along road leading up the hill from McCarthy's Ferry. See Fig. 3, Pl. XIV.
2. Laminated clays, reddish and yellowish, containing an indurated greensand marl with Hatchetigbee fossils, exposed in hill above the bluff and intervening between the strata seen in the river bluff and the aluminous rocks of the Buhrstone seen higher up the hill.
3. Sandy clays interstratified with clays less sandy, light gray, along the whole length of the bluff. There are parallel bands of much darker brown clays... 55 feet.
4. Laminated clays and sands, firm and compact at base, and forming projecting ledge.. 5 feet.
5. Pyritous sandy clays, with two or three bands of darker color, indurated in places, forming bowlders ....20 feet.

PLATE XVI.

ILLUSTRATING THE WOOD'S BLUFF OR BASHI AND BELL'S LANDING SECTIONS OF THE LIGNITIC, AND INCLUDING THE LOWER BEDS OF THE HATCHETIGBEE SECTION.

FIG. 1. *Section at Yellow Bluff, Alabama River.*

1. Gray, sandy clays, with cross bedded sands. Forty feet seen in one exposure in river bank and 90 feet more seen on the hills within 1 mile of the river. Only the lower 40 feet occurring at river are here shown....................40 feet.
2. Greensand marl, Wood's Bluff fossils ....6 feet or more.
3. Blue clay ....1 foot.
4. Gray, sandy clays of slightly purple tinge, containing four or five thin seams of lignite ....40 feet.
5. Reddish, cross bedded sand ....20 feet.
6. Lignitic clay and lignite..2 feet.
7. Reddish sands, slightly laminated....................................15 feet.
8. Gray, sandy clays, laminated, forming perpendicular cliff ....25 feet.
9. Greensand marl, indurating into bowlders, Bell's Landing fossils..........8 feet.
10. Greenish, ferruginous sands interlaminated with thin sheets of clay to water level..7 feet.

FIG. 2. *Section at Bell's Landing, Alabama River.*

1. Yellowish, cross bedded sands ....15 feet.
2. Lignite ....2 feet.
3. Laminated, sandy clays, with a few large, bowlder like concretions........10 feet.
4. Yellow, stratified sands, alternating with gray, sandy clays...............15 feet.
5. Gray, sandy clays, laminated ....15 feet.
6. Greensand marl, forming bowlders, gigantic shells....................6 to 10 feet.
7. Dark gray, laminated, sandy clays.....................................25 feet.
8. Sandy, clay marl ....1 to 2 feet.
9. Dark gray, sandy clay to water level....................................4 feet.

FIG. 3. *Section at Peebles's Landing, Alabama River.*

1. Yellowish sands ....1 to 2 feet.
2. Lignite and lignitic clay..2 feet.
3. Reddish sands, laminated...10 feet.
4. Gray clays and sands, variously interstratified.................about 30 feet.
5. Greensand marl, forming bowlders, Bell's Landing fossils ....8 feet.
6. Dark gray, sandy, laminated clays ....25 feet.
7. Strata covered by second bottom deposits, down to water level............20 feet.

FIG. 4. *Section at Gregg's Landing, Alabama River.*

1. Greensand marl, forming bowlders, Bell's Landing fossils..............8 to 10 feet.
2. Gray, sandy, laminated clays ....20 to 25 feet.
3. Sandy clay marl, fossiliferous.....................................4 to 5 feet.
4. Laminated, sandy clays to water level ....10 feet.

FIG. 5. *Section at Lower Peach Tree Landing, Alabama River.*

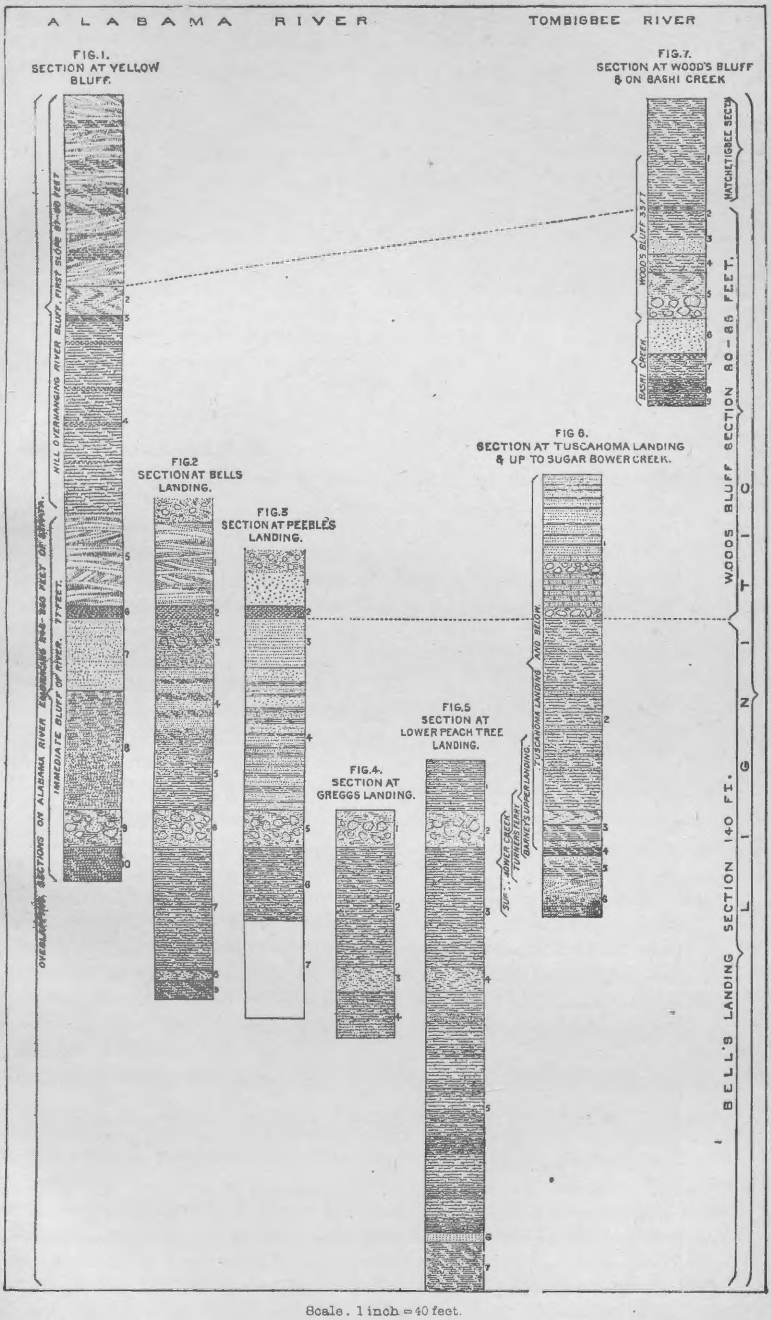
1. Sandy, laminated clays, top of bluff ....10 feet.
2. Greensand marl, forming bowlders, Bell's Landing fossils..............8 to 10 feet.
3. Laminated, sandy clays of gray color but with reddish layers ....20 to 25 feet.
4. Bluish, sandy clay marl, Gregg's Landing fossils.....................4 to 5 feet.
5. Sandy clays of prevailing gray color, varying in degree of sandiness and coarseness of lamination. No fossils observed ....50 feet.
6. Fossiliferous greensand..1 foot.
7. Gray, sandy clays to water level..10 feet.

FIG. 6. *Section at Tuscahoma Landing and up to Shuquabowa Creek, Tombigbee River.*

1. Laminated sands, interstratified with clayey sheets, upper part; lower part, indurated sands with two lines of ferruginous, bowlderlike concretions, one at base, the other ten feet above ....30 feet.
2. Light bluish gray, sandy clays, striped with somewhat harder projecting bands or ledges ....35 to 40 feet.
3. Greensand marl, Bell's Landing fossils; three feet blue clay in middle..6 to 7 feet.
4. Bluish black, massive clay ....2 feet.
5. Sands passing into sandy clays below ....5 feet.
6. Lighter colored, cross bedded sands above, with sands and clay interstratified below ....8 feet.

FIG. 7. *Section at Wood's Bluff and Bashi Creek, Tombigbee River.*

1. Dark gray to brown and purple, sandy clays, lower beds of Hatchetigbee section.
2. Bluish, sandy, fossiliferous clay, red on surface, hard ledge on top ....3 feet.
3. Bluish, sandy clay (like 2), but not fossiliferous, passing into greensand below .7 feet.
4. Fossiliferous, clayey greensand...3 feet.
5. Greensand marl, main bed, with a stratum of ponderous oyster shells; highly fossiliferous sands forming bowlders ....10 feet.
6. Fossiliferous greensand, loose and easily washed out, forming caves below the bowlders ....8 feet.
7. Thin bands of lignite over greenish, non-fossiliferous, clayey sands.........5 feet.
8. Laminated, gray, sandy clays ....3 to 4 feet.
9. Lignite ....1 foot.



Scale. 1 inch = 40 feet.

WOOD'S BLUFF OR BASHI SECTION AND BELL'S LANDING SECTION OF THE LIGNITIC

PLATE XVII.

ILLUSTRATING THE NANAFALIA AND COAL BLUFF SECTIONS OF THE LIGNITIC.

FIG. 1. *Sections at Gullette's Bluff and Coal Bluff, Alabama River.*

Gullette's Bluff.

1. Red loam, sand, &c., of Drift, at the top of the bluff....................10 feet.
2. Indurated, glauconitic clay..3 feet.
3. Gray, sandy clays, alternately thinly laminated and heavy bedded or massive...12 feet.
4. Very green, glauconitic sand...2 feet.
5. Gray, sandy clays, similar to No. 3 above.............................20 feet.
6. Fossiliferous, glauconitic sand, first of *Gryphœa thirsæ* beds...............3 feet.
7. Compact, yellowish sands with *Gryphœa thirsæ*, capped by hard ledge, forming vertical cliff...13 feet.
8. Indurated sands...2 feet.
9. White, cross bedded sands...12 feet.
10. Bluish sands in a vertical cliff; contains *Gryphœa thirsæ;* indurated ledge in middle and at bottom of the bed..20 feet.
11. Bluish, clayey sands, with *Gryphœa*.................................10 feet.
12. Sands with *Gryphœa thirsæ*, traversed by several indurated ledges down to water level; darker colored and more clayey below.......................20 feet.

Between mouth of Pursley Creek and Coal Bluff.

13. Greensand, mouth of Pursley Creek..................................5 feet.
14. Sands capped with indurated ledge..................................3 feet.
15. Clayey sands; indurated sandy ledges at top and in the midst..............6 feet.
16. Indurated greensand..3 feet.
17. Softer greensand, out of which caves are washed........................5 feet.
18. Greensand of firmer texture, with 1 foot of brownish sand at bottom......8 feet.
19. Lignite of Coal Bluff...4 feet.
20. Firm, gray, sandy clays appearing just above Coal Bluff Landing.........10 feet.

FIG. 2. *Section in Grampian Hills, 2 to 3 miles south of Camden, Wilcox County.*

1. Light colored sand and clayey rocks 2 feet, and 2 feet sandstone with shell casts..4 feet.
2. Gray clays, indurated, closely resembling Buhrstone................10 to 15 feet.
3. Light colored, sandy clay rock, full of shell casts, chiefly *Turritella*........5 feet.
4. Gray crumbling clays, weathering into small bits......................5 to 6 feet.
5. Hard, glauconitic, sandy clay with shell casts breaking into cuboidal blocks..3 feet.
6. Gray, indurated clays, glauconitic in places, and like some of the Buhrstone clays..12 to 15 feet.
7. Greensand, with casts of *Gryphœa thirsæ*...............................2 feet.
8. Greensand, in places converted into a yellowish sand, holding the *Gryphœa thirsæ*..10 feet.

9. Yellow sands, with *Gryphæa* .... 5 feet.
10. Bed of *Gryphæa* shells .... 1 foot.
11. Yellow sands, with *Gryphæa*, and forming bowlders, 6 to 8 feet; in all .. 12 to 14 feet.

FIG. 3. *Section on Pursley Creek, Wilcox County, Camden and Black's Bluff road.*

1. Red loam, sand, &c., of Drift.
2. Dark colored, crumbling sandy clays .... 5 feet.
3. Sands, with *Gryphæa thirsæ* and a few other fossils .... 5 to 7 feet.
4. Thin bedded sands and sandy clays .... 15 feet.
5. Yellowish gray, cross bedded sands, with indurated bowlders of same materials; these sands hold also thin, lenticular sheets of gray clay .... 25 feet.
6. Interstratified sands and clays of grayish color, with shades of yellow, rather thin-bedded .... 15 feet.
7. Gray, sandy clays in banks of Pursley Creek .... 6 feet.
8. Lignite or lignitic clay, bed of Pursley Creek.

FIG. 4. *Strata exposed on Tombigbee River from mouth of Horse Creek up to Nanafalia; also section on Landrum's Creek.*

Mouth of Horse Creek to Gay's Landing.

1. Gray, sandy clays, forming banks of river between mouth of Horse Creek and Williams's Gin, and directly overlying the bed at the last named place . 20 feet.
2. Gray, sandy clays, thin bedded, and in joint planes, passing below into a hard, sandy ledge .... 8 feet.
3. Indurated greensand, with *Gryphæa thirsæ* .... 2 feet.
4. Dark blue black clays, with thin, firm ledges .... 6 feet.
5. Indurated sands, with *Gryphæa thirsæ* .... 2 feet.
6. Bluish black, sandy clays .... 3 feet.
7. Greensand, with *Gryphæa thirsæ*, passing below into gray, sandy clay . 5 feet or more.

Lott's Ferry.

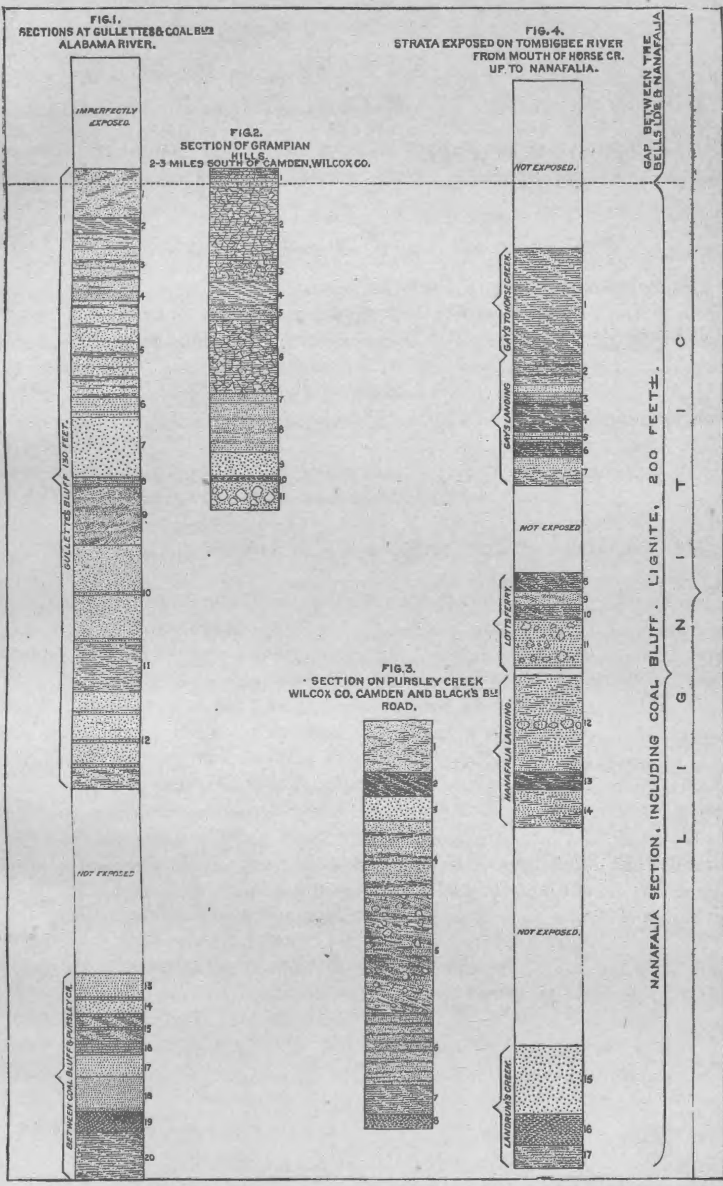
8. Black, sandy clay, fossiliferous .... 4 feet.
9. Sands, with *Gryphæa thirsæ*, cross bedded in places .... 3 feet.
10. Dark gray, sandy clay, with few fossils .... 3 feet.
11. Greensand, with *Gryphæa thirsæ*, forming hard bowlders in places .... 10 feet.

Nanafalia Landing.

12. Greensand marl, highly fossiliferous, with *Gryphæa thirsæ* and other forms; line of indurated, projecting bowlders along central part of bed .... 20 feet.
13. Dark blue, almost black, laminated clay, devoid of fossils .... 3 to 4 feet.
14. Bluish greensand marl, highly fossiliferous below, *Gryphæa thirsæ* and other forms .... 8 to 10 feet

Landrum's Creek.

15. Bluish, micaceous sands overlying lignite on Landrum's Creek, near Nanafalia Bluff .... 15 feet.
16. Lignite exposed on Landrum's Creek .... 7 feet.
17. Gray, sandy clays .... 5 feet.



Scale: 1 inch = 40 feet.

NANAFALIA AND COAL BLUFF SECTION OF THE LIGNITIC.

PLATE XVIII.

ILLUSTRATING THE OAK HILL, PINE BARREN SERIES, WHICH INCLUDES THE NAHEOLA AND MATTHEWS'S LANDING, BLACK BLUFF. AND THE MIDWAY SECTIONS OF THE LIGNITIC.

FIG. 1. *Section at Oak Hill and on Pine Barren Creek.*

1. Cross bedded sands and thinly laminated clays, much weathered and with difficulty distinguished from the red loam &c. of the Drift................25 feet.
2. Gray, cross bedded sands, with thin laminæ of dark gray clay. These beds are much the same as the preceding, but are much less weathered................40 feet.
3. Cross bedded and laminated sands, yellowish................1½ feet.
4. Thin bedded, gray, laminated clays, interstratified with thin ledges of cross bedded sands................30 feet.
5. Sands 1 foot, clays 1 foot, sands 1 foot................3 feet.
6. Gray clays interstratified with cross bedded sands................6 feet.
7. Gray, cross bedded sands................3 feet.
8. Gray clay, breaking up into cuboidal blocks, and interstratified with sandy ledges................15 feet.
9. Black to gray, micaceous sands, with the fossils of Matthews's Landing, dark at top, lighter and glauconitic below................7 feet.
10. Glauconitic sandy ledge, calcareous................1 foot.
11. Yellowish, calcareous sands, with phosphatic and white lime concretions; crustacean remains in upper 5 feet; several hard, shaly ledges................12 feet.
12. Glauconitic, sandy shales, with indurated ledge at top................10 feet.
13. Sandy, shaly beds, with indurated ledges................6 feet.
14. Hard, yellowish, sandy limestone, phosphatic................3 feet.
15. Yellowish, calcareous, clayey sands, with white lime concretions, grayer and more clayey below; Black Bluff fossils abundant................15 feet.
16. Black, calcareous clays, gray on weathered surfaces; Black Bluff fossils, especially in upper part. This forms basis of the prairie soils................20 feet.
17. Hard, grayish white limestone, used for chimneys, &c., containing a large *Nautilus*................10 feet.
18. Calcareous sands forming basis of the sandy prairies................6 feet.
19. Hard, yellow, crystalline limestone, with Ostrea, *Turritella Mortoni*, and *Venericardia planicosta*................8 feet.
20. Yellow, micaceous sands, with Ripley fossils—seen on road above Palmer's Mill................55 feet.
21. Bluish gray, calcareous sands, with projecting sandy ledges, on Pine Barren Creek................15 feet.

FIG. 2. *Section on the Alabama River.*

Coal Bluff.

1. Bluish greensand over lignite.
2. Coal Bluff lignite................4 feet.
3. Compact, clayey sand underlying lignite.

Burford's Landing.

4. Gray, cross bedded sands alternating with laminæ of gray clay, Burford's Landing..10 feet.

Walnut Bluff.

5. Light yellowish, cross bedded sands, Walnut Bluff.

Turkey Creek to Clifton.

6. Gray or bluish, sandy clays, forming river banks from mouth of Turkey Creek to Clifton, of variable dip and hence of undetermined thickness.
7. Dark, gray sandy clays at Clifton and above, nearly to mouth of Dickson's Creek. The beginning of the Matthews's Landing beds........................10 feet.

Matthews's Landing.

8. Bluish black, micaceous sands, highly fossiliferous....................5 to 6 feet.
9. Yellowish gray, calcareous sands, indurating into bowlders................ 4 feet.
10. Bluish black, micaceous sands, fossiliferous, compact and clayey below.7 to 8 feet.

Midway.

11. Black, calcareous clay overlying the Nautilus Rock.................... 5 feet.
12. Gray, argillaceous limestone, with numerous large *Enclimatoceras Ulrichi*..10 feet.

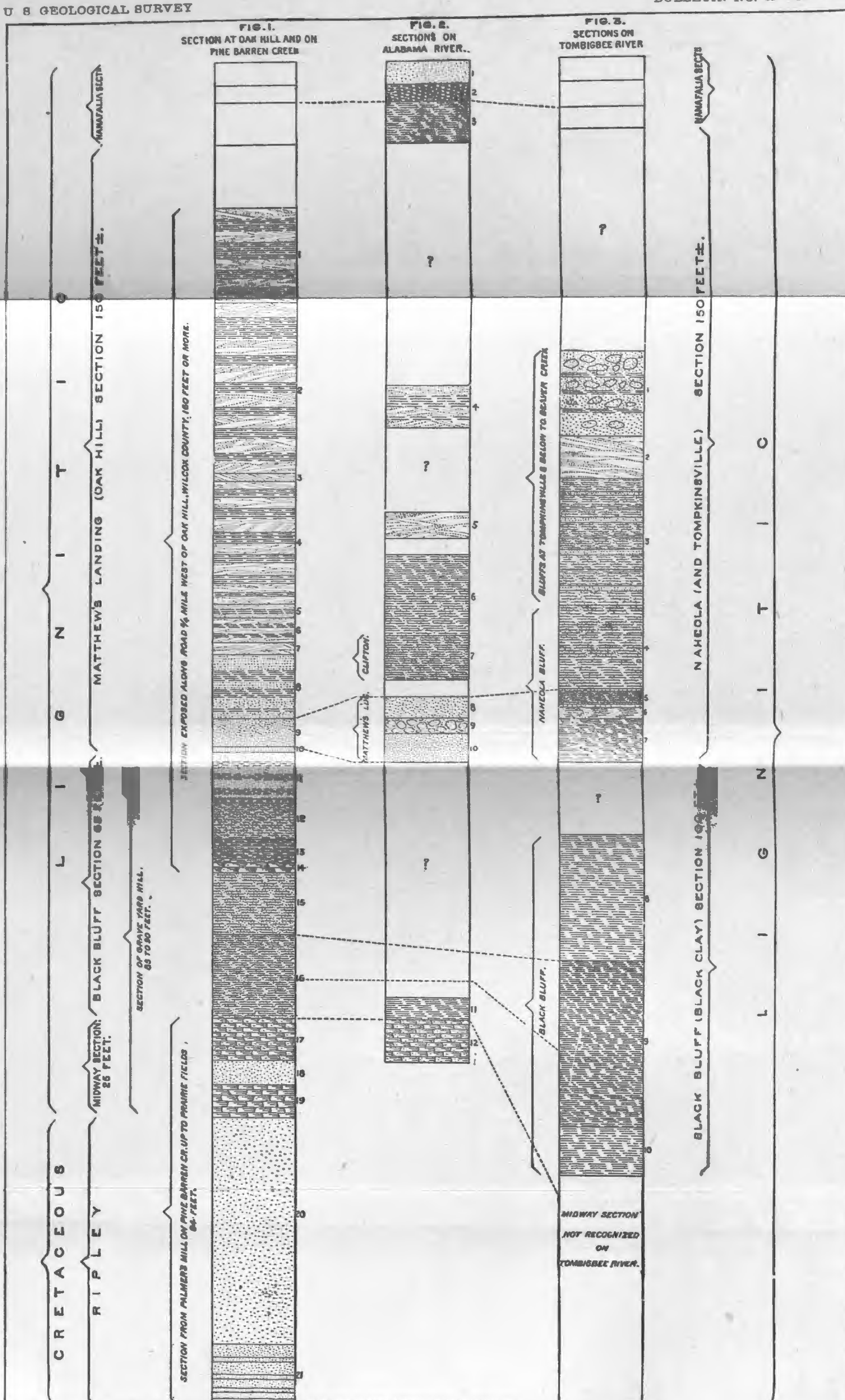
FIG. 3. *Sections on the Tombigbee River.*

Mouth of Beaver Creek to Naheola.

1. Coarse grained, micaceous sands, with projecting bowlders of indurated sand or sandstones, no fossils, thin clay partings at intervals, seen just below Tompkinsville..20 feet.
2. Cross bedded sands, just below Tompkinsville..........................10 feet.
3. Gray, sandy clays, alternating with ledges of indurated sand and thin clay partings, Tompkinsville Bluff, no fossils..................................30 feet.
4. Gray, sandy clays, with ledges of sandier texture and lighter color.......20 feet.
5. Black, sandy clay, with indurated ledge of greensand above, in all....... 3 feet.
6. Greensand marl, capped with hard ledge, ferruginous.................... 3 feet.
7. Black, slaty clay, recurring at all the bluffs above this to Black Bluff.....10 feet.

Black Bluff.

8. Yellowish clay at top of bluff. This clay is the basis of the Flatwoods.....30 feet.
9. Black, slaty clay, strongly calcareous, fossiliferous (Black Bluff fossils)...40 feet. The lower part of this division is covered with singularly shaped concretions of limonite.
10. Brownish, shaly clay to the water level...............................10 feet.



Scale: 1 inch = 40 feet

OAK HILL, PINE BARREN SERIES OF THE LIGNITIC, INCLUDING THE NAHEOLA AND MATTHEWS'S LANDING, THE BLACK BLUFF, AND THE MIDWAY SECTIONS.

PLATE XIX.

ILLUSTRATING THE RIPLEY FORMATION OF THE CRETACEOUS GROUP, ALABAMA AND TOMBIGBEE RIVERS.

FIG. 1. *Palmer's Mill, on Pine Barren Creek.*

1. Hard, yellow, crystalline limestone, with *Ostrea*, corals, *Turritella Mortoni*, *Venericardia planicosta*, &c ....8 feet.
2. Yellow, micaceous sands, with Ripley fossils, seen on road above Palmer's Mill ....55 feet.
3. Bluish gray, calcareous sands, with several projecting sandy ledges, to level of Pine Barren Creek........15 feet.

FIG. 2. *Bridgeport Landing, Alabama River.*

1. Yellow, crystalline limestone, seen in Camden-Bridgeport road.
2. Yellowish, micaceous sands, forming basis of the hills back of the Bridgeport Bluff.
3. Yellow, clayey sands, top of bluff at Bridgeport Landing ....10 feet.
4. Coarse, yellow sands........10 feet.
5. Laminated, gray clays........1 foot.
6. Ledge of dark gray, sandy clay........1 foot.
7. Dark gray, nearly black, sandy, micaceous clays, with hard, projecting, sandy ledges at intervals of 3 to 4 feet........22 feet.
8. Projecting, sandy ledge........1½ feet.
9. Dark gray, sandy clays ....3 feet.
10. Sandy ledge........1 foot.
11. Dark gray, sandy clays, with two hard, sandy ledges, to water level......10 feet.

FIG. 3. *Canton Landing, Alabama River.*

1. Yellow sands, forming basis of the fertile soils of the Canton Bend.
2. Yellowish gray, micaceous, and calcareous sands, in beds averaging 3 to 5 feet in thickness and separated by hard, sandy ledges, which shale off on weathering; these beds appear at intervals on hillside immediately back of the river bluff, being in part covered by débris ....100 feet.
   In places the clayey sands have a dark blue color.
3. Yellow, calcareous, sandy clays, like the preceding, with hard ledges above and below; top of river bluff........10 feet.
4. Bluish, micaceous, sandy clays, the counterpart of those at Bridgeport, with two projecting, sandy ledges ....12 feet.
5. Light gray, calcareous sands, holding indurated, irregular masses, phosphatized shell casts, &c.; sandstone ledge at base........6 feet.
6. Bluish gray, sandy clay, 5 feet thick, underlaid by more sandy bed, with phosphatized shell casts, nodules, &c ....8 feet.
7. Bluish, argillaceous limestone, with *Exogyra*, *Gryphæa*, and phosphatic casts.3 feet.
8. Calcareous sands, with variety of fossils........3 feet.

FIG. 4. *Foster's Creek, in Gee's Bend, Alabama River.*

1. Yellowish, calcareous, sandy clay soil, with growth of red cedars.
2. Dark gray, micaceous, sandy clays, like those of Bridgeport, with hard, sandier ledges of lighter color at intervals of 5 to 6 feet. The lowermost of these beds contain the small Moscow *Gryphæa*........30 feet.

3. Impure limestone, glauconitic, with phosphatized shell casts &c. ....5 feet.
4. Coarse, calcareous sandstone ledge ....2 feet.
5. Bluish, sandy, argillaceous limestone, no fossils at top, but filled in its lower and middle parts with shells and phosphatized shell casts. The materials of this bed vary from argillaceous limestone to calcareous sands...................20 feet.
6. Brown, phosphatic limestone ....1 foot.
7. Argillaceous sandstone ....1 foot.

FIG. 5. *Section on Tear Up Creek, Wilcox County, Alabama River.*

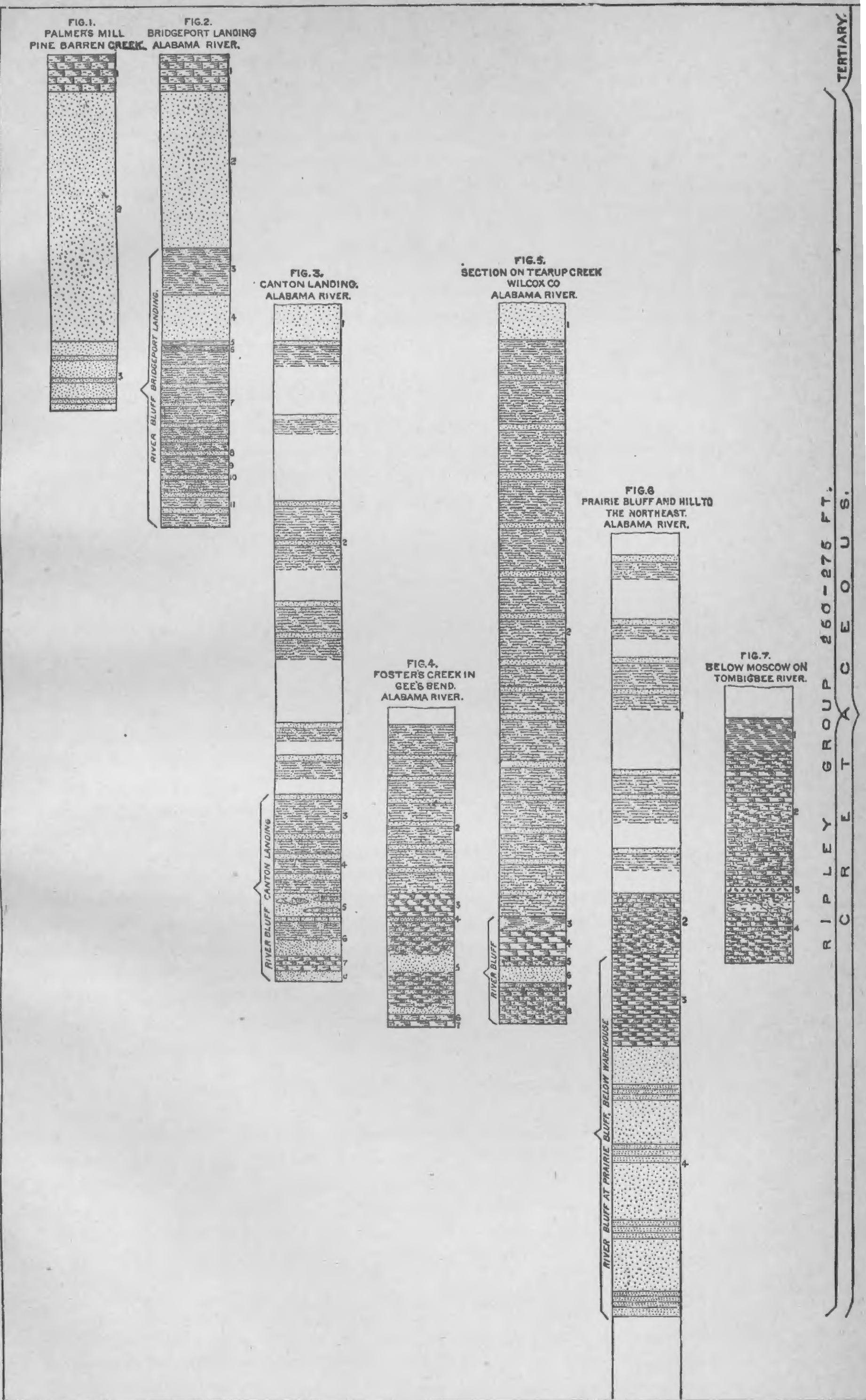
1. Yellow sands at base of McNeill's Mountain.
2. Dark bluish gray, sandy, micaceous clays, with hard, projecting ledges at intervals of 3 or 4 feet. These beds are exposed in channel of Tear Up Creek between the river and the foot of McNeill's Mountain, distance about 1 mile. The thickness not measured, but here placed equal to that noticed at Canton Landing ....100 feet.
3. Ferruginous, sandy marl, full of Ripley fossils ....3 feet.
4. Firm white limestone; no fossils observed ....6 feet.
5. White limestone, with a few fossils ....2 feet.
6. Sandy, calcareous beds, with fine fossils ....4 feet.
7. Sandy, indurated limestone ledge ....1 to 2 feet.
8. Calcareous limestone, with *Exogyra costata* &c ....8 feet.

FIG. 6. *Prairie Bluff and hill to the northeast, Alabama River.*

1. Yellowish, calcareous, and micaceous sands, with hard, sandy ledges at intervals of 4 or 5 feet, forming the hill northeast of Prairie Bluff towards Rehoboth. In some places, where less exposed to weathering, the color of the sandy clays is dark bluish, like those of Bridgeport. The strata of this hill are in appearance identical with those above the river bluff at the old Canton Landing, not a continuous section ....75 to 100 feet, perhaps more.
2. Impure limestone, holding phosphatized shell casts &c., outcropping on the bluff north of warehouse; extended thickness..........................12 to 15 feet.
3. Bluish limestone, with shell casts and *Exogyra costata*, *Gryphæa mutabilis*, &c., forming top of bluff below warehouse; two hard ledges in it ....20 feet.
4. Sands, traversed by indurated bands of calcareous sand, holding *Exogyra costata* and *Gryphæa mutabilis* chiefly. The sands are white above and dark blue near water level, but the blue sands become white where they crop out up the river near the top of the bluff. Sands contain great numbers of *Ostrea falcata*.....50 to 60 feet.

FIG. 7. *Below Moscow, on the Tombigbee River.*

1. Black, shaly clay, devoid of fossils, joints filled with calcite, at mouth of Sucarnochie Creek ....6 to 8 feet.
2. Dark blue, shaly, argillaceous limestone and thin, projecting, harder ledges..30 feet.
3. Ledges of small *Gryphæa* shells ....1 foot.
4. Hard, impure limestones, with *Exogyra costata* and *Gryphæa mutabilis;* irregular, concretionary, sandy ledge above, with comminuted shells, below which a projecting ledge, with many phosphatized shell casts..........................15 feet.



Scale 1 inch = 40 feet.

RIPLEY GROUP OF THE CRETACEOUS FORMATION.

PLATE XX.

ILLUSTRATING THE PHOSPHATIC GREENSANDS (TOMBIGBEE SAND) AT BASE OF THE ROTTEN LIMESTONE, TOGETHER WITH THE UPPER STRATA OF THE EUTAW FORMATION OF THE CRETACEOUS GROUP.

FIG. 1. *Bluff at Erie, Tuscaloosa River.*

1. Rotten Limestone of the usual character....................................30 feet.
2. Indurated ledge, calcareous sand, glauconitic and phosphatic, containing oyster shells..7feet.
3. Yellowish sands, containing shells in upper part..............................8 feet.
4. Ledge of shells ....1 foot.
5. Yellowish, glauconitic sands; more glauconitic below.........................5 feet.
6. Sandy ledge, with shells...1 foot.
7. Greensand, cross bedded..4 feet.
8. Laminated, blue clay, projecting...2 feet.
9. Phosphatic greensand ....1 foot.

FIG. 2. *McAlpine's Ferry, Tuscaloosa River.*

1. Rotten Limestone of variable thickness, with covering of Drift.
2. Calcareous sands, indurated, containing shells, mostly oysters..........6 to 8 feet.
3. Sands. ....8 to 10 feet.
4. Greensand to water level ....6 feet or more.

FIG. 3. *Choctaw Bluff, Tuscaloosa River.*

1. Rotten Limestone, with Inocerami and reptilian bones, covering of Drift ..20 feet.
2. Indurated calcareous sands, full of shells, glauconitic; upper part = the "Concrete Sand" of Winchell...6 to 7 feet.
3. Yellowish, cross bedded sands, containing oyster shells in upper part, more glauconitic and devoid of fossils below...15 feet.
4. Glauconitic sands and small oyster shells ....1 foot.
5. Phosphatic greensand ....6 to 8 feet.

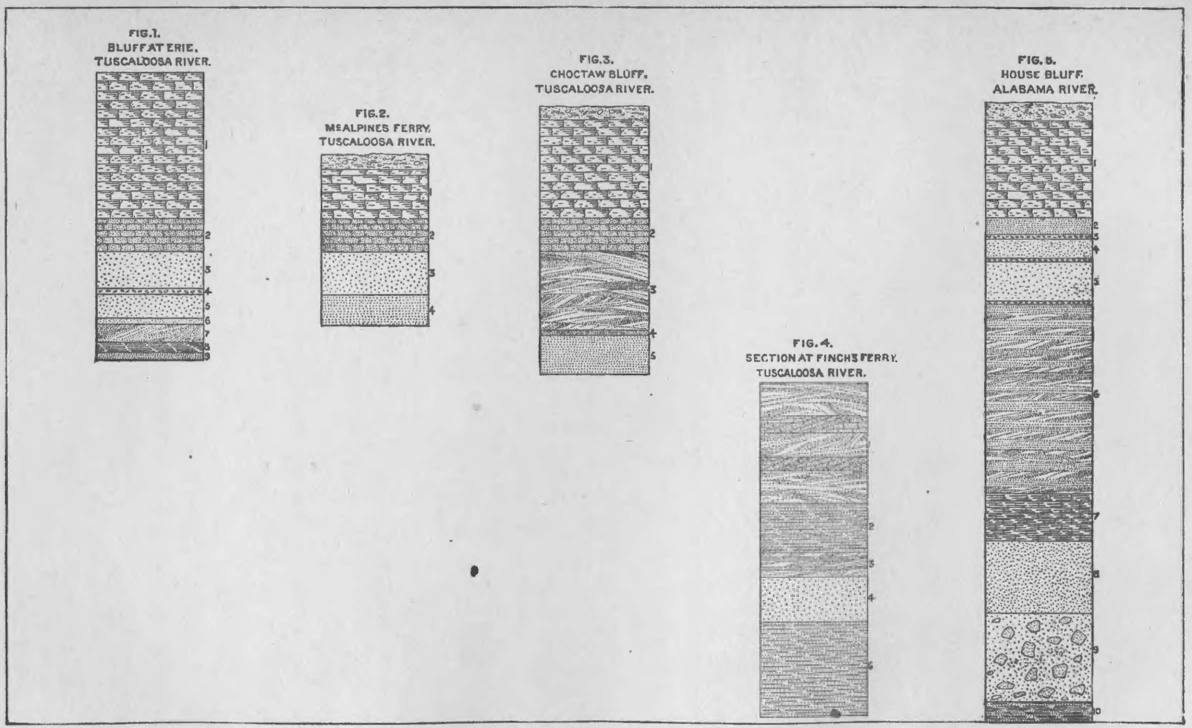
FIG. 4. *Section at Finch's Ferry, Tuscaloosa River.*

1. Yellowish, cross bedded sands, with indurated bands at intervals; contains a few casts of shells, mostly oysters, and pieces of silicified wood...............25 feet.
2. Laminated, blue clays, with sand between the laminæ.........................10 feet.
3. Alternations of cross bedded sand and blue, laminated clay....................5 feet.
4. Bluish, glauconitic sands...10 feet.
5. Laminated, blue clays, the laminæ separated by sand ....20 feet.

FIG. 5. *House Bluff, Alabama River.*

1. Rotten Limestone ....20 feet.
2. Greensand, with phosphatic nodules...4 feet.
3. Bed of shells in sand..1 foot.

4. Light colored sands, with irregular deposits of shells and shell bed at base. 5 feet.
5. Sands, with layer of shells at base .... 9 feet.
6. Alternating beds of horizontally laminated and cross bedded sands, yellow (glauconitic), the separate beds from 1 to 2 feet thick, marked with streaks deeply colored by iron .... 40 feet.
7. Laminated clays (soapstone), devoid of fossils .... 10 feet.
8. Blue, micaceous sands, no fossils observed .... 15 feet.
9. Light colored sands, with large, bowlder-like concretion .... 20 feet.
10. Alternations of laminated clays and blue sands to water level.



Scale: 1 inch = 40 feet.

PHOSPHATIC GREENSANDS AT THE BASE OF THE ROTTEN LIMESTONE.

PLATE XXI.

GENERAL SECTION OF TERTIARY AND CRETACEOUS STRATA OF ALABAMA, AS EXPOSED ALONG THE ALABAMA, TOMBIGBEE, AND TUSCALOOSA RIVERS.

COLUMN 1. *Exposures inland near Alabama River. (Supplementary to Alabama River section.)*

Hills back of Yellow Bluff.

1. Gray, sandy clays, alternating with cross bedded sands, seen in hill back of Yellow Bluff; barometric measurement........90 feet.
2. Gray, sandy clays, alternating with cross bedded sands, like the preceding; seen in hill at top of Yellow Bluff........40 feet.
3. Greensand marl, Wood's Bluff........6 to 15 feet.
4. Gray, sandy clays of purple tinge, including four or five thin seams of lignite. Top of Yellow Bluff........40 feet.

Grampian Hills.

5. Gray, sandy clays, indurated, in part glauconitic, and filled with shell casts, chiefly of Turritella, in part closely resembling Buhrstone clays........47 to 50 feet.
6. Glauconitic sands, with *Gryphæa thirsæ*, several indurated bands........25 feet.

On Pursley Creek.

7. Glauconitic sands, with *Gryphæa thirsæ*, clayey above........12 feet.
8. Laminated sand and sandy clays........15 feet.
9. Yellowish gray, cross bedded sands, indurating, with bowlders, inclosing lenticular sheets of clay........25 feet.
10. Gray sands and clays, interstratified, glauconitic; lignite at base; seen in Pursley Creek........20 feet.

Oak Hill, Graveyard Hill, and Pine Barren Creek.

11. Gray, sandy clays, cross bedded sands, and thin, laminated clays in many alternations........108 feet.
12. Gray clay, breaking into cuboidal blocks, 15 feet, passing into black clay marl, Matthews's Landing........23 feet.
13. Yellowish, calcareous sands and sandy shales, with hard ledges and 3 feet hard, yellowish, phosphatic, sandy limestone at base........31 feet.
14. Yellow, calcareous clays, passing below into black, all holding Black Bluff fossils........35 feet.
15. Argillaceous white limestone; Nautilus Rock 10 feet, with 6 feet calcareous sands below........16 feet.
16. Crystalline limestone and Turritella Rock........8 to 9 feet.
17. Yellowish, micaceous sand, with Ripley fossils........55 feet.
18. Bluish gray, calcareous sands, hard, projecting layers........15 feet.

Near Vinton, Autauga County.

19. Thinly laminated, white and pink and purple clays, with small percentage of pink, purple, and yellow sand........30 feet.
20. Purple and mottled clays 12 feet, red sands 5 feet, and white and yellow, laminated clays 8 feet........25 feet.
21. Variegated pink and micaceous sands........6 feet.
22. Mottled, yellow and purple, sandy clays and sands, on the banks of Mulberry Creek........20 feet.

Soap Hill, Bibb County.

23. Clayey sands in several ledges........10 feet.
24. Cross bedded, yellowish white sands, indurating into sandstones at intervals........30 feet.

25. Laminated, gray clay, with partings of sand 10 feet, overlying 40 feet of laminated clays and cross bedded sands ....50 feet.
26. Laminated, gray, sandy clays, with leaf impressions, sand at base ....20 feet.

Near Tuscaloosa.

27. Variegated, purple sands, sheet of ferruginous sandstone on top ....8 feet.
28. Purple clay, with partings of sand...10 feet.
29. Gray, yellow sands and clays, ferruginous ledge on top.......................8 feet.
30. Thin bed of lignite in clays, over gray mass. Not seen ....about 20 feet.
31. Purple clays, with two ledges of sandy iron ore...........................40 to 50 feet.

COLUMN 2. *Section exposed on Alabama River.*

Marshall's Landing to Lisbon.

1. *Vicksburg.* White Limestone, with *Orbitoides Mantelli*, hill back of Claiborne, also back from river, from Marshall's Landing to Gainestown..at least 140 feet.
2. *Jackson.* Argillaceous White Limestone, with bones of *Zeuglodon Cetoides*, phosphatic nodules, and marls, from Claiborne to Marshall's Landing.......60 feet.
3. Scutella bed, followed by coarse, ferruginous sands, of which 17 feet is highly fossiliferous; hard, sandy ledge at base ....30 feet.
4. Calcareous clay, alternating with greensand containing *Ostrea sellæformis*.25 feet.
5. Light gray, calcareous sands, traversed by hard, sandy ledges, clayey in part, *Ostrea sellæformis*, characteristic greensand, and shells at base.....................35 feet.
6. Blue clay, passing into greensand, upper half with few fossils, lower half highly fossiliferous...22 feet.
7. Calcareous, clayey sands ....9 feet.
8. Coarse ferruginous marl 3 feet, followed by 20 feet of light yellow sands, few fossils..23 feet.
9. Bluish, jointed clay ....12 feet.

Hamilton's Landing.

10. Light colored, aluminous sandstones, claystones, and silicious sandstones..75 feet.

Yellow Bluff, Bell's Landing, and Lower Peach Tree.

11. Reddish, cross bedded sands, 2 feet lignite at base..........................22 feet.
12. Laminated, sandy clays, gray color..15 feet.
13. Yellow sands, passing below into gray, laminated, sandy clays..............25 feet.
14. Greensand marl, Bell's Landing ....10 feet.
15. Gray, laminated, sandy clays 22 to 25 feet, passing into clay marl, Gregg's Landing, 5 feet..30 feet.
16. Sandy clays of prevailing gray color, varying in degree of sandiness and coarseness of lamination, 1 foot greensand marl at base..........................50 feet.
17. Gray, sandy clays..10 feet.

Gullette's Landing.

18. Gray, sandy clays, alternately thin, laminated, and heavy bedded; indurated by glauconitic clay on top and greensand bed in middle ....37 feet.
19. Glauconitic sands, with *Gryphæa thirsæ*, indurated ledges passing through beds...18 feet.
20. White, cross bedded sands...12 feet.
21. Bluish, clayey, glauconitic sands, with *Gryphæa thirsæ*, several hard ledges.50 feet.

Pursley Creek to Coal Bluff.

22. Glauconitic, clayey sands of varying degree of hardness, bed of lignite 4 feet (Coal Bluff) at base ....35 feet.
23. Gray, sandy clays ....10 feet.

Burford's Landing.

24. Gray clay, cross bedded sands, Burford's Landing ....10 feet.

Walnut Bluff to Clifton.

25. Gray, sandy clays, forming river banks from Walnut Bluff to Clifton...35 (?) feet.

Matthews's Landing.

26. Black, sandy clay marl, micaceous, Matthews's Landing..................20 feet.

Midway to Prairie Bluff.

27. Black clay, Midway ....5 feet.
28. Argillaceous White Limestone (Nautilus Rock) ....10 feet.
29. Crystalline limestone (*Turritella*) back of Bridgeport.
30. Yellowish, micaceous sand (Ripley fossils) at Bridgeport and hills back of landing...55 feet.
31. Dark bluish gray, sandy, micaceous clays, weathering into yellowish shales, with indurated, sandy, projecting ledges at intervals of 5 to 10 feet throughout whole thickness, exposed at Bridgport, Tear Up Creek, Canton Landing, and hills back of Prairie Bluff, and in Gee's Bend ....100 feet.
32. Bluish, argillaceous limestone, with phosphatized shell casts &c., Ripley formation ....30 to 35 feet.
33. Sands of various colors, dark blue, gray to white, traversed by indurated bands of calcareous sands with Cretaceous shells...............................60 feet.

Rotten Limestone, Bridgeport to House Bluff.

34. Highly argillaceous limestone, with ledges holding many shells (*Ostrea, Gryphæa, Exogyra*) ....1,000 feet.

House Bluff.

35. Hard, calcareous sands, with fossils strongly phosphatic in part..........20 feet.
36. Alternating layers of horizontally laminated and cross bedded, yellowish (glauconitic) sands...40 feet.
37. Laminated, blue clays...10 feet.
38. Blue, micaceous sands ....15 feet.
39. Light colored, micaceous sands ....20 feet.
40. Laminated clays and blue sands, thickness not determined.

COLUMN 3. *Section exposed on the Tombigbee (including the Tuscaloosa) River.*

St. Stephens and Baker's Bluff.

1. *Vicksburg.* White Limestone, with *Orbitoides Mantelli*, forms upper 70 feet of Saint Stephens Bluff, upper part of Baker's Hill, and greater part of river bluffs, down to Oven Bluff...140 feet.
2. *Jackson.* Argillaceous White Limestone lower part of Saint Stephens and Baker's Bluffs ....60 feet.
3. Scutella bed, underlaid by coarse greensand and Claiborne fossiliferous sands ....15 feet.

Coffeeville Landing.

4. Yellowish gray, calcareous sands, with *Ostrea sellæformis*, clayey in part, traversed by hard, sandy ledges, greensand, with comminuted shells at base ......35 feet.
5. Bluish clay ....7 feet.

Hatchetigbee to mouth of Bashi Creek.

6. Aluminous sandstones, claystones, &c., of jointed structure, forming at White Bluff a perpendicular cliff..115 feet.
7. Brown clays, sandy, non-fossiliferous, 30 feet, followed by 3 feet marl and 15 feet purplish brown, sandy clays; then 28 feet of sands, striped with brown clays and inclosing two beds with marine shells; in all.........................75 to 76 feet.
8. Dark gray, sandy clays, striped with brown or purple, sandy clays. Very few fossils exposed at Davis's Bluff, White's Bluff, and McCarthy's Bluff...100 feet.

9. Clayey marl, passing into a greensand marl 18 feet thick ....31 feet.
10. Gray, clayey sands, with four or more thin seams of lignite..............25 feet.

Tuscahoma to Shuquabowa Creek.

11. Laminated sands and indurated sands, with bowlders.......................30 feet.
12. Gray, sandy clays, striped with somewhat harder, projecting ledges..35 to 40 feet.
13. Greensand marl (Bell's Landing) ....7 feet.
14. Sandy, laminated clays ....15 feet.

Horse Creek to Gay's Landing.

15. Gray, sandy clays, rather thin bedded; hard, sandy ledge at base..........28 feet.
16. Glauconitic sands and clays, with *Gryphœa thirsæ*..........................18 feet.

Lott's Ferry to Nanafalia.

17. Glauconitic sands, with *Gryphœa thirsæ*, at Lott's Ferry, Eureka Landing, and Nanafalia Landing ....35 feet.
18. Black clay, passing into greensand marl, with *Gryphœa thirsæ* ....18 feet.

Landrum's Creek.

19. Black, micaceous, glauconitic sands..15 feet.
20. Lignite 7 feet and 5 feet gray clay below....................................12 feet.

Tompkinsville to Naheola.

21. Gray, sandy clays, cross bedded sands and laminated clays in many alternations ....80 feet.
22. Greensand marl (Naheola), with black clay below ....20 feet.

Naheola to Black Bluff.

23. Between Naheola and Black Bluff, black clays..............thickness unknown.
24. Yellowish clays 30 feet, underlaid by 50 feet of black in dark brown, slaty, fossiliferous clays, Black Bluff fossils..80 feet.

Moscow.

25. Dark blue or black, sandy clays, with indurated bands, calcareous below, passing into an argillaceous limestone 16 to 18 feet, with phosphatized shell casts ....55 feet.

Rotten Limestone, Moscow to Choctaw Bluff.

26. Argillaceous limestone, with hard ledges, holding many shells (*Ostrea*, *Exogyra*, *Gryphœa*) ....1,000 feet.

Choctaw Bluff to Big Log Shoals.

27. Hard, calcareous sands, highly fossiliferous, 6 to 8 feet; thin, yellow, cross bedded sands, 15 feet; and below this a phosphatic greensand, 8 to 10 feet..about 25 feet.
28. Cross bedded, glauconitic sands, with thin clay partings, yellowish color prevailing ....40 feet.
29. Dark gray, laminated, sandy clays, alternating with bluish sands...15 to 20 feet.
30. Laminated sands and clays, alternating with cross bedded sands...... 40(?) feet.
31. Compact, micaceous sands, cross-bedded sands, laminated clays, in many alternations, including two small beds of pebbles and thin bed of lignitic matter...60(?) feet.

White's Bluff.

32. Purple and mottled clays, 10 feet, with 15 feet of yellow, micaceous sands below..25 feet.

Steele's Bluff.

33. Purple and mottled clays, 10 feet, with 10 feet light yellow, coarse, cross bedded pebbly (chert) sands ....20 feet.

Williford's.

34. Purple and mottled clays ....10 feet.

Mrs. Prince's.

35. Purple and mottled clays......10 feet.

Saunders's Ferry to Tuscaloosa.

36. Dark gray, laminated clays, sandy partings, 25 feet, and gray sands, indurated, 15 feet, at Venable's and near Saunders's Ferry......40 feet.
37. Sandy clays, with leaf impressions, black scales like graphite, fragments of lignitized stems.

COLUMN 4. *Exposures inland near Tombigbee and Tuscaloosa Rivers.* (*Supplementary to the Tombigbee River section.*)

Salt Mountain.

1. White Limestone, in part crystalline, filled with masses of coral......150 feet.
2. Orbitoidal White Limestone......20 feet.

Hills west of McCarthy's Ferry.

3. Aluminous sands, indurated clays or claystones, silicious sandstones, &c., forming hills west of McCarthy's Ferry, in Choctaw County, 270 feet in one exposure, with 15 feet laminated clays at base; in all......285 feet.

Bladen Springs boring.

4. Loose surface materials, varying slightly in color and texture......80 feet.
5. Alternations of blue and sandy marl (clay), with indurated blue ledge 5 feet thick at base......81 feet.
6. Soft, clayey marl......23 feet.
7. Greensand, with shells, 3 feet, followed by 22 feet alternating hard and soft beds, the latter fossiliferous, water bearing......25 feet.
8. Marls or blue clays......46 feet.
9. Brown and blue marls (clays) in many alternations (lignitic ?)......21 feet.
10. Blue marls or clays, with 2 feet of greensand at base......61 feet.
11. Lignite, 5 feet, followed by 19 feet of brown, tough marl (clay)......24 feet.
12. Blue, sandy marl, with many varieties of shells; *Venericardia planicosta* recognized......23 feet.
13. Blue, sandy marl (clay)......58 feet.
14. Brown marl (clay) 5 feet, with 32 feet blue marl below......37 feet.
15. Greensand marl, 9 feet, followed by 37 feet of blue marl (clay). At 500 feet water was struck, which flowed 10 feet above surface......46 feet.
16. Brown clay marl, 19 feet, followed by 15 feet blue clay, with greensand, containing shells......34 feet.
17. Brown marl, resembling soapstone; contains shells; stream of water near bottom which flowed 30 feet above surface......50 feet.
18. Gray, sandy marl, with shells......15 feet.
19. Gray, sandy marl, with shells; more clayey than preceding......64 feet.
20. Very tough, blue marl (clay), at base of which a thin layer of white sand and then a thin layer of greensand......71 feet.
21. Brown marl (clay) 5 feet, followed by alternating beds of clay and sand, mostly sand (*first salt water*)......20 feet.
22. Alternations of gray and brown sand, with marl (clay)......26 feet.
23. Tough, blue marl, clay (*big vein of salt water*)......13 feet.
24. Sand and clay alternating......14 feet.
25. A kind of white limestone (?) containing mica, passing below into 3 feet blue, sandy marl, containing shells......28 feet.
26. Blue marl (clay) 14 feet, followed by 14 feet of blue marl and sand, numerous shells......28 feet.
27. Marl, 12 feet, with streaks of sand, followed by brown sand and blue marl, 12 feet......24 feet.

28. Greenish rock, chalky above, hard below....................................11 feet.
29. Sandstone 4 feet, followed by 25 feet quicksand, of white, blue, and gray colors (*strong stream of salt water*)..29 feet.
30. Marls or clays, mostly of grayish or light brown colors, with several ledges of extremely hard rock, e. g., one 2 feet thick at 966 feet, one 1 foot thick at 971 feet, one 3 inches thick at 978 feet, one 1 foot thick at 1,009 feet ....137 feet.
31. Tough black clay, 2 feet, followed by 99 feet of dark blue clay, some of it quite hard and firm; some very soft and sticky ....99 feet.
32. Snuff colored clay, soft and sticky ....13 feet.
33. Gray sand and shells 12 feet, followed by 5 feet soft, sandy clay.............17 feet.
34. Hard ledge 4 inches at top, below which 125 feet of moderately hard, grayish or blue rock, with scarcely any change in color or texture, to bottom of boring; no shells observed; Rotten Limestone ....probably 125 feet.

Livingston artesian well boring.

35. Soft, blue, argillaceous Rotten Limestone, thickly set with shells and containing iron pyrites ....180 feet.
36. Hard, white limestone, with few shells..50 feet.
37. Hard, blue limestone 7 feet, followed by 68 feet of pure, bluish white limestone, with few if any shells ....75 feet.
38. Very hard, white limestone, stratum of oyster shells near top.............55 feet.
39. Light blue limestone, not so hard as preceding.................................47 feet.
40. Bluish brown limestone, filled with small shells, rather sandy.............58 feet.
41. Hard, white limestone...105 feet.
42. Soft, blue limestone, 2 feet brown rock at top......................................22 feet.
43. Rather soft, brownish blue limestone..78 feet.
44. Very soft, blue limestone, hard ledge at top ....11 feet.
45. White limestone, moderately soft, with occasional slight changes in color and hardness...250 feet.
46. Hard sandstone 6 feet, 10 feet sand, water bearing, and 1 foot sandstone...17 feet.
47. Coarse greensand 38 feet, sandstone 2 feet, greensand 25 feet, sandstone 2 feet, and greensand again 18 feet, water bearing at 1,005 feet..........................85 feet.
48. Fine greensand, flint layer on top ....10 feet.

Strata of Tuscaloosa formation.

Near Havana.

49. Yellow sand and pebbles 10 feet, overlying 30 feet of variegated, pink and purple, micaceous, cross bedded sands, near Havana ....40 feet.

Big Sandy Creek.

50. Purple and mottled clays seen along road leading up hill from Big Sandy Creek ....50 feet.
51. Light yellow sands and pebbles 15 feet, with 8 feet dark gray, laminated clay, with lignitized trunk, Big Sandy Creek ....23 feet.

Little Sandy Creek.

52. Yellow, micaceous sands, overlying dark gray, micaceous, laminated clays..8 feet.
53. (Belongs to a recent formation.)

Tuscaloosa City.

54. Dark gray, laminated clays, with leaf impressions..................................8 feet.
55. Light colored, sharp, cross bedded sands ....20 feet.

Scale: 1 inch = 200 feet.

GENERAL SECTION OF TERTIARY AND CRETACEOUS STRATA OF ALABAMA, AS EXPOSED ALONG THE ALABAMA, TOMBIGBEE, AND TUSCALOOSA RIVERS.

INDEX.

ADVERTISEMENT.

[Bulletin No. 44.]

The publications of the United States Geological Survey are issued in accordance with the statute approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

Except in those cases in which an extra number of any publication has been supplied to the Survey by special resolution of Congress or has been ordered by the Secretary of the Interior, this Office has no copies for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Second Annual Report of the United States Geological Survey, 1880-'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. 1884. 8°. xxxii, 473 pp. 85 pl. and maps.

V. Fifth Annual Report of the United States Geological Survey, 1883-'84, by J. W. Powell. 1885. 8°. xxxvi, 469 pp. 58 pl. and maps.

VI. Sixth Annual Report of the United States Geological Survey, 1884-'85, by J. W. Powell. 1886. 8°. xxix, 570 pp. 65 pl. and maps.

The Seventh and Eighth Annual Reports are in press.

MONOGRAPHS.

Of the Monographs, Nos. II, III, IV, V, VI, VII, VIII, IX, X, XI, and XII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt. U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. Copper-Bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price $1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price $1.05.

VII. Silver-Lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price $1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price $1.10.

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. xx, 338 pp. 35 pl. Price $1.15.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh, 1885. 4°. xviii, 243 pp. 56 l. 56 pl. Price $2.70.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. xiv, 288 pp. 46 pl. Price $1.75.

XII. Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. 1886. 4°. xxix, 770 pp. 45 pl. and atlas of 35 sheets folio. Price $8.40.

The following is in press:

XIII. Geology of the Quicksilver Deposits of the Pacific Slope, with atlas, by George F. Becker.

The following are in preparation:

I. The Precious Metals, by Clarence King.

— Gasteropoda of the New Jersey Cretaceous and Eocene Marls, by R. P. Whitfield.

— Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.

— Lake Bonneville, by G. K. Gilbert.

— Sauropoda, by Prof. O. C. Marsh.

— Stegosauria, by Prof. O. C. Marsh.

— Brontotheridæ, by Prof. O. C. Marsh.

— The Penokee-Gogebic Iron-Bearing Series of North Wisconsin and Michigan, by Roland D. Irving.

— Younger Mesozoic Flora of Virginia, by William M. Fontaine.

— Description of New Fossil Plants from the Dakota Group, by Leo Lesquereux.

— Report on the Denver Coal Basin, by S. F. Emmons.

— Report on Silver Cliff and Ten-Mile Mining District, Colorado, by S. F. Emmons.

— Flora of the Dakota Group, by J. S. Newberry.

— The Fossil Fishes and Fossil Plants of the Triassic Rocks of New Jersey and the Connecticut Valley, by J. S. Newberry.

BULLETINS.

Each of the Bulletins contains but one paper and is complete in itself. They are, however, numbered in a continuous series, and may be bound in volumes of convenient size. To facilitate this, each Bulletin has two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 44 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining values of troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A Catalogue of Geological Maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.

9. Report of work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary Studies, by Charles D. Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin, with Descriptions of New Forms, by R. Ellsworth Call. Introduced by a Sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 3 pl. Price 5 cents.

13. Boundaries of the United States and of the several States and Territories, by Henry Gannett. 1885. 8°. 135 pp. Price 10 cents.

14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.

15. On the Mesozoic and Cenozoic Paleontology of California, by Charles A. White. 1885. 8°. 33 pp. Price 5 cents.

16. On the Higher Devonian Faunas of Ontario County, New York, by John M. Clarke. 1885. 8°. 86 pp. 3 pl. Price 5 cents.

ADVERTISEMENT.

17. On the Development of Crystallization in the Igneous Rocks of Washoe, Nevada, by Arnold Hague and Joseph P. Iddings. 1885. 8°. 44 pp. Price 5 cents.

18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Charles A. White. 1885. 8°. 26 pp. 3 pl. Price 5 cents.

19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. 28 pp. Price 5 cents.

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. 114 pp. 1 pl. Price 10 cents.

21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. 16 pp. 5 pl. Price 5 cents.

22. On New Cretaceous Fossils from California, by Charles A. White. 1885. 8°. 25 pp. 5 pl. Price 5 cents.

23. Observations on the Junction between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point, Lake Superior, by R. D. Irving and T. C. Chamberlin. 1885. 8°. 124 pp. 17 pl. Price 15 cents.

24. List of Marine Mollusca, comprising the Quaternary fossils and recent forms from American Localities between Cape Hatteras and Cape Roque, including the Bermudas, by William H. Dall. 1885. 8°. 336 pp. Price 25 cents.

25. The Present Technical Condition of the Steel Industry of the United States, by Phineas Barnes. 1885. 8°. 85 pp. Price 10 cents.

26. Copper Smelting, by Henry M. Howe. 1885. 8°. 107 pp. Price 10 cents.

27. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1884–'85. 1886. 8°. 80 pp. Price 10 cents.

28. The Gabbros and Associated Hornblende Rocks occurring in the Neighborhood of Baltimore, Md., by George H. Williams. 1886. 8°. 78 pp. 4 pl. Price 10 cents.

29. On the Fresh-water Invertebrates of the North American Jurassic, by Charles A. White. 1886. 8°. 41 pp. 4 pl. Price 5 cents.

30. Second Contribution to the Studies on the Cambrian Faunas of North America, by Charles D. Walcott. 1886. 8°. 369 pp. 33 pl. Price 25 cents.

31. A Systematic Review of our Present Knowledge of Fossil Insects, including Myriapods and Arachnids, by Samuel H. Scudder. 1886. 8°. 128 pp. Price 15 cents.

32. Lists and Analyses of the Mineral Springs of the United States; a Preliminary Study, by Albert C. Peale. 1886. 8°. 235 pp. Price 20 cents.

33. Notes on the Geology of Northern California, by Joseph S. Diller. 1886. 8°. 23 pp. Price 5 cents.

34. On the relation of the Laramie Molluscan Fauna to that of the succeeding Fresh-water Eocene and other groups, by Charles A. White. 1886. 8°. 54 pp. 5 pl. Price 10 cents.

35. The Physical Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1886. 8°. 62 pp. Price 10 cents.

36. Subsidence of Fine Solid Particles in Liquids, by Carl Barus. 1887. 8°. 58 pp. Price 10 cents.

37. Types of the Laramie Flora, by Lester F. Ward. 1887. 8°. 354 pp. 57 pl. Price 25 cents.

38. Peridotite of Elliott County, Kentucky, by Joseph S. Diller. 1887. 8°. 31 pp. 1 pl. Price 5 cents.

39. The Upper Beaches and Deltas of the Glacial Lake Agassiz, by Warren Upham. 1887. 8°. 84 pp. 1 pl. Price 10 cents.

40. Changes in River Courses in Washington Territory due to Glaciation, by Bailey Willis. 1886. 8°. 10 pp. 4 pl. Price 5 cents.

41. Fossil Faunas of the Upper Devonian—the Genesee Section, New York, by Henry S. Williams. 1886. 8°. 121 pp. 4 pl. Price 15 cents.

42. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1885–'86. F. W. Clarke, chief chemist. 1887. 8°. 152 pp. 1 pl. Price 15 cents.

43. On the Tertiary and Cretaceous Strata of the Tuscaloosa, Tombigbee, and Alabama Rivers, by Eugene A. Smith and Lawrence C. Johnson. 1887. 8°. 189 pp. 21 pl. Price 15 cents.

44. Bibliography of North American Geology for 1886, by Nelson H. Darton. 1887. 8°. 35 pp. Price 5 cents.

Numbers 1 to 6 of the Bulletins form Volume I; Numbers 7 to 14, Volume II; Numbers 15 to 23, Volume III; Numbers 24 to 30, Volume IV; Numbers 31 to 36, Volume V; Numbers 37 to 41, Volume VI. Volume VII is not yet complete.

The following are in press:

45. Present Condition of Knowledge of the Geology of Texas, by Robert T. Hill. 1887. 8°.

46. The Nature and Origin of Deposits of Phosphate of Lime, by R. A. F. Penrose, jr.

47. Analyses of Waters of Yellowstone National Park, by F. A. Gooch and J. E. Whitfield.

48. On the Form and Position of the Sea Level, by R. S. Woodward.

49. On the Latitude and Longitude of Points in Missouri, Kansas, and New Mexico, by R. S. Woodward.

50. Invertebrate Fossils from California, Oregon, Washington Territory, and Alaska, by C. A. White.

51. On the Subaërial Decay of Rocks and the Origin of the Red Color of Certain Formations, by Israel C. Russell.

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 44

WASHINGTON
GOVERNMENT PRINTING OFFICE
1887

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

BIBLIOGRAPHY

OF

NORTH AMERICAN GEOLOGY FOR 1886

BY

NELSON H. DARTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1887

BIBLIOGRAPHY OF NORTH AMERICAN GEOLOGY FOR 1886.

BY NELSON H. DARTON.

INTRODUCTION.

The scope of this work embraces papers or parts of papers relating to the geology of North America issued during the year 1886 or bearing that date. The publications and book lists of the following institutions were examined in its preparation:

American Academy, Proceedings, vol. 21.
American Association for the Advancement of Science, Proceedings, 1885 and 1886.
American Institute of Mining Engineers, Transactions.
American Journal of Science.
American Museum of Natural History, Bulletin, December 28, 1886.
American Naturalist.
American Philosophical Society, Proceedings, vol. 23, Nos. 121 and 123.
Appalachia, vol. 4, No. 3.
Boston Society of Natural History, Proceedings, April 1, 1885, to March 17, 1886.
Brookville Society of Natural History, Proceedings, Nos. 1 and 2.
Buffalo Society of Natural Sciences, Bulletin, vol. 5, Nos. 1 and 2.
California Academy of Sciences, Bulletin, vol. 2, No. 5.
Canadian Institute, Proceedings, vol. 3, Nos. 3 and 4, vol. 4, No. 1.
Canadian Record of Science, vol. 2, Nos. 1–4.
Cincinnati Society of Natural History, Journal, vol. 8, No. 9.
Colorado Scientific Society, Transactions, vol. 2, part 1.
Denison University, Bulletin, No. 1.
Des Moines Academy of Science, Bulletin, vol. 1, No. 1.
Elisha Mitchell Natural History Society, Journal, 1885–'86.
Engineering and Mining Journal, vol. 42.
Essex Institute, Bulletin, vol. 17, Nos. 4–6; vol. 18, Nos. 1–6.
Geological Society, Quarterly Journal.
Gesellschaft für Erdkunde zu Berlin, Zeitschrift, vol. 21.
Hamilton Association, Journal, vol. 1, No. 2.
Iowa Historical Record, October, 1885, January and July, 1886.
Johns Hopkins University, Circulars, Nos. 43–52.
Manitoba Historical and Scientific Society, No. 20.
Nature.
Neues Jahrbuch.
New Brunswick Natural History Society, Bulletin, No. 5.
New York Academy of Sciences, Annals, vol. 3, Nos. 9–12.
New York Academy of Sciences, Transactions, vol. 5, Nos. 1–6.
Pacific Coast Technical Society, Proceedings, vol. 3, Nos. 1, 3, and 4.

Philadelphia Academy of Sciences, Proceedings, January to September, 1886.
Popular Science Monthly.
Royal Society of Canada, Transactions, vol. 3.
Saint Louis Academy of Science, Proceedings, vol. 4, No. 4.
School of Mines Quarterly, vol. 7 and vol. 8, No. 1.
Science.
Science Observer, vol. 4.
Scientific American Supplement, vol. 22.
Sedalia Natural History Society, Bulletin, No. 1.
Staten Island Scientific Association, Proceedings, January to November, 1886.
Tenth Census: Report on Mining Industries of the United States.
United States Geological Survey, Publications.
Vassar Brothers' Institute, Proceedings, vol. 3, part 1.
Washburn College, Bulletin, vol. 1, Nos. 2-7.
Washington Philosophical Society, Bulletin, vol. 8.
Wisconsin Academy of Science, Transactions, vol. 6.
Wyoming Historical and Geological Society, Publications, vol. 2, part 2.
Yorkshire Geological and Polytechnic Society, Proceedings, 1885.

The proceedings of a number of small local societies and several trade journals were not examined. Reasonable care has been taken to avoid errors and omissions, but no doubt some will be found.

The index references given with the titles are solely for the purpose of facilitating search for papers of which only the title or principal subject is known.

I am indebted to the following gentlemen for suggestions and information: Mr. McGee, Mr. Gilbert, Mr. Marcou, Professor Chamberlin, and Mr. Pilling.

WASHINGTON, *March* 15, 1887.

BIBLIOGRAPHY.

A.

Alabama, geologic survey report, SMITH.
iron and coal, PORTER.
iron mines, CHAUVENET.
Raccoon coal field, GIBSON.
Tertiary, ALDRICH, LANGDON, SMITH.
Warrior coal field, MCCALLEY.

Alaska, Quaternary, ALLEN.

ALDRICH (T. H.). Preliminary report upon the Tertiary fossils of Alabama and Mississippi.

Geol. Survey of Ala. Bulletin No. 1, pp. 15–60 and 6 pls.
Describes the fossiliferous beds and states opinion as to their horizon and equivalency.

ALLEN (Henry T.). Copper River, Alaska, glacial action.

Science, vol. 8, pp. 145–146.
Describes present glaciers and some of the evidences of former ones.

Anticosti, fossils, GRANT.

Archean, at Wallbridge Mine, Canada, CHAPMAN.
of Lake of the Woods region, LAWSON.
of New Jersey, BRITTON.
of Northwestern States, IRVING.
schistose structure, LAWSON.

Arkansas, coal fields, HARVEY.
minerals and rocks, HARVEY.

Artesian wells, CHAMBERLIN.

ASHBURNER (Charles A.). Borings for oil in Jackson and Abbott Townships, Potter County.

Annual Report of the Geol. Survey of Pa. for 1885, pp. 82–94.
Gives the well records and discusses the horizon and dip of the oil sands.

ASHBURNER (C. A.)—Continued.

—— Description of the Archbald potholes; also of the Buried Valley of Newport Creek near Nanticoke, with special reference to the "Nanticoke mine disaster" of December, 1885.

Annual Report of the Geol. Survey of Pa. for 1885, pp. 615–636.
General statements about glaciation. Detailed description of the pot-holes and discussion of their cause. Discusses the thickness and distribution of drift near Nanticoke.

—— Geologic distribution of natural gas in the United States.

Am. Inst. Mining Engineers, Trans. Oct. 1886, pp. 32 and maps.
Gives a general description of the geology of the oil bearing and associated strata in Pennsylvania, Ohio, and New York.

—— Report on the Brandywine Summit kaolin bed, Delaware County.

Annual Report of the Geol. Survey of Pa. for 1885, pp. 592–614.
Detailed description of the kaolin and associated beds and modes of mining and preparing the clay for market. Calls attention to the relation of kaolinization to bedding and cleavage planes and to the drainage of the district.

—— Report on the Tipton Run coal openings, Blair County (coal beds in the Pocono formation, No. X).

Annual Report of the Geol. Survey of Pa. for 1885, pp. 250–268.
Describes the outcrops and workings in the coal beds and discusses their structure and geologic relations to the containing and associated formations.

—— Report on the Wyoming Valley Carboniferous limestone beds.

Wyoming Hist. and Geol. Soc. Proc. vol. 2, pp. 254–264.

ASHBURNER (C. A.)—Continued.

Describes other Carboniferous limestone beds in Pennsylvania and the occurrence and horizon of the beds in the Wyoming Valley.

—— Second report of progress in the anthracite coal regions.

Annual Report of the Geol. Survey of Pa. for 1885, pp. 269-490 and 2 pls.

General description of topography; structural geology, stratigraphic geology and mining, classification and composition of coals; report of progress in the various coal fields of the region; description of the geologic, mine, and columnar section sheet and on the basins and anticlines in the northern field; report on the Bernice coal basin, and report on Wyoming Valley limestone beds, also published in Wyoming Hist. and Geol. Soc. Proc. vol. 2, pp. 254-277.

Atlantic, age of basin, DANA, NEWBERRY, HULL.

geology of, DAWSON.

AUGHEY (Samuel). Annual report of the territorial geologist to the governor of Wyoming, 1886, pp. 120, 8°, Laramie, 1886.

Describes the condition of mines and some geologic features in the Silver Crown, Seminole, Ferris, Sweetwater, Owl Creek, Bridger, and Cummins City mining districts; the iron ore deposits and their geologic position; the petroleum district: its geology, structure, geologic history, genesis of its oil, climate, productions, &c.; and a list of minerals of the territory.

B.

BAILEY (L. W.). Explorations and surveys in portions of the counties of Carleton, Victoria, York, and Northumberland, N. B.

Annual Report of the Geol. Survey of Canada, vol. 1, n. s. G, pp. 29 and map.

Describes the stratigraphic and structural features of the several formations and discusses their age &c. The paper is accompanied by a colored geologic map.

—— Geology and geologists in New Brunswick.

Canadian Rec. Sci. vol. 2, pp. 93-96.

Discusses Wadsworth's criticisms on the geologic work in New Brunswick and the structure and stratigraphic relations of the Cambrian.

BARCENA (Mariano). The fossil man of Peñon, Mexico.

Am. Nat. vol. 20, pp. 633-635.

Describes beds in which the remains occur and does not consider them modern travertine as supposed by Newberry.

BARRIS (W. H.). A defense of our local geology.

Davenport Acad. Sci. Proc. vol. 5, pp. 15-22.

BECKER (George F.). Cretaceous metamorphic rocks of California.

Am. Jour. Sci. III, vol. 31, pp. 348-357.

Describes beds near Neocomian in age lying upon the Archean of the Coast Ranges and altered to crystalline and serpentine rocks, of which the petrographic character is described. Discusses modes and means of metamorphism.

Reviewed in Nature, vol. 34, pp. 80-81.

BECKER (G. F.)—Continued.

—— The Washoe rocks.

California Acad. Sci. Bulletin No. 6, pp. 93-120.

Reviews Hague and Iddings's criticisms and describes the mode of occurrence and petrography of the rocks in question. Discusses conditions of extrusion and crystallization and the extension of the various rock masses in the district.

BELL (Robert). The mineral resources of the Hudson Bay territories.

Am. Inst. Mining Eng. Trans., vol. 15, p. 9.

Describes the geology of the district.

—— The mode of occurrence of apatite in Canada.

Canadian Inst. Proc. vol. 21, pp. 294-302.

Describes the lithology of the apatite bearing rocks.

—— Observations on the geology, zoölogy, and botany of Hudson Strait and Bay.

Annual Report of the Geol. Survey of Canada, vol. 1, n. s. DD, pp. 26.

Describes some features of the crystalline, Silurian, Devonian, volcanic, and drift formations. Discusses source of volcanic rocks and evidence of glaciation.

BENTON (Edward R.). Notes on the samples of iron ore collected in Maryland.

Tenth Census: Report on the Mining Industries of the United States, pp. 245-250.

Detailed description of some of the deposits.

—— Notes on samples of iron ore collected in Northern New England.

Tenth Census: Report on the Mining Industries of the United States, pp. 79-82.

BENTON (E. R.)—Continued.

Describes some features of the formations associated with the ore beds.

—— Notes on the samples of iron ore collected in Virginia.

Tenth Census: Report on the Mining Industries of the United States, pp. 261-268.

Description of the geology and structure of the formations associated with some of the ore beds.

BISHOP (I. P.). On certain fossiliferous limestones of Columbia Co., N. Y., and their relation to the Hudson River shales and the Taconic system.

Am. Jour. Sci. III, vol. 32, pp. 438-441.

Describes the occurrence of Trenton fossils near Chatham and the stratigraphic relations of the rocks to others in the same general district.

Bonneville, Lake, GILBERT.

BOYD (C. R.). The economic geology of the Bristol and Big Stone gap section of Tennessee and Virginia.

Am. Inst. Mining Eng. Trans. vol. 15, p. 8.

Describes the geology and structure of the district in considerable detail.

BRAINERD (Alfred F.). Note on a deposit of fire sand in Clinton County, N. Y.

Am. Inst. Mining Eng. Trans. vol. 15, p. 3.

Describes the occurrence of the sand and its composition. It overlies Potsdam sandstone.

BRANNER (John C.). [Geologic map of Indiana, colored according to the scheme of the International Geologic Congress. 2 by 4 inches.]

Accompanied by a circular, in French, calling attention to inapplicability of the scheme of coloration for the representation of the subdivisions of the formations in Indiana.

—— Glaciation of the Lackawanna Valley.

Am. Ass. Adv. Sci. Proc. vol. 34, pp. 212-214.

Gives the result of many observations of drift striæ and notes some of variable directions. Discusses the effect of topography on the ice flow.

—— The glaciation of parts of Wyoming and Lackawanna Valleys.

Am. Phil. Soc. Proc. vol. 23, pp. 337-357.

Describes and gives maps of the topography and discusses its relation to the ice flow. Describes the drift and discusses the mechanical effect of the glaciation. Discusses pot-holes, striæ, and preglacial and postglacial drainage.

BRANNER (J. C.)—Continued.

—— The thickness of the ice in Northeastern Pennsylvania during the glacial epoch.

Am. Jour. Sci. III, vol. 32, pp. 362-366.

Finds glacial striæ on top of "North Knob" of Elk Mountains, contrary to the statement of Lewis and Wright that this and other eminences of similar height were above the line of glaciation.

British Columbia, glacial shell-beds, LAMPLUGH.

BRITTON (N. L.). [Additional notes on the geology of Staten Island, New York.]

Nat. Sci. Ass. of Staten Island, Proc. Oct. 1886.

Describes structure of serpentine and occurrence of other rocks. Discusses the relation to similar rocks of New York Island and the deposition and metamorphism of the original sediments. Calls attention to areas of preglacial drift and a driftless area north of the terminal moraine.

—— [Fossil leaves in the Cretaceous of Staten Island.]

N. Y. Acad. Sci. vol. 5, pp. 28-29.

Describes the section including the bed in which the leaves were found.

—— [Notes on the occurrence of a schistose series of crystalline rocks in the midst of the Adirondacks.]

N. Y. Acad. Sci. Trans. vol. 5, p. 72.

—— [On the drift at the south end of tunnel at Tompkinsville, N. Y.]

Nat. Sci. Ass. of Staten Island, Proc. April, 1886.

Describes contact of morainal and stratified drift. Discusses coast subsidence and the terraces of the Hudson River.

—— [Remarks on the floor of the Trias of New Jersey and the lithology of the tide water gneisses.]

N. Y. Acad. Sci. vol. 5, pp. 19 and 20.

Calls attention to the occurrence of slate and limestone on the northwestern border of the Trias and to the similarity of the gneisses of Central Park, New York, and Fairmount Park, Philadelphia.

—— [Report on the study of the Archean rocks of New Jersey.]

Annual Report of the State Geologist [of N. J.] for 1885, pp. 36-55.

After a historical résumé of former investigations there is given a description of the rocks,

BRITTON (N. L.)—Continued.
their distribution and structure, relation of stratified and unstratified deposits, the occurrence of magnetites and the contact phenomena with the Paleozoic rocks. The question of age is briefly discussed. The paper is accompanied by sections, with exaggerated vertical scales, showing the structure along a number of lines across the formation.

—— [Results of a cruise along the shores of Staten Island and New Jersey.]

Nat. Sci. Ass. of Staten Island, Proc. Sept. 1886.

Calls attention to the exposures of drift and Cretaceous and to changes of coast line.

BRÖGGER (W. C.). On alderen af Olenelluszonen i Nordamerica.

Geol. Förening. Stockholm, Band 8, Hefte 1-4, p. 182.
Not seen.

Buffalo and Chicago, CLAYPOLE.

Buried Valley. See **Quaternary**.

C.

CAMPBELL (J. L. and H. D.). Wm. B. Rogers' Geology of the Virginias. A review.

Am. Jour. Sci. III, vol. 30, pp. 357-374; vol. 31, pp. 193-202.
Briefly states Rogers's views and gives much additional information, beginning with the Archean and taking up each formation in turn.

CARLL (John F.). Preliminary report on oil and gas.

Annual Report of the Geol. Survey of Pa. for 1885, pp. 1-81 and map. Abstract in Petroleum Age, vol. 5, No. 10, Nov. 1886, pp. 1467-1469.
Discusses the horizon of the oil sands, the relations of gas to oil, theories of oil and gas, and the present status of knowledge in regard to the geology of oil.

CARTER (Oscar C. S.). Ores, minerals, and geology of Montgomery County, Pa., pp. 32 and map, imp. 8° [Philadelphia, 1886].

From History of Montgomery County.

Description of deposits of copper, iron, and graphite, and of the more general geologic features as described by others. The paper is accompanied by a colored geologic map slightly differing in some respects from that published officially.

Central America, volcanic rocks, HAGUE.

CHALMERS (R.). Preliminary report on the surface geology of New Brunswick.

Annual Report of the Geol. Survey of Canada, vol. 1, n. s. GG, pp. 58 and map.

Issued separately in 1885.

CHAMBERLIN (T. C.). An inventory of our glacial drift.

Am. Ass. Adv. Sci. Proc. vol. 35, pp. 195-211. Abstract in Science, vol. 8, pp. 156-159.

Describes outline of drift limit, points out varying character of margins of drift sheets, and states conclusions drawn therefrom as to different periods of formation and agencies of deposition. Discusses terminal, interlobate, and lateral moraines; till tumuli; mammillary and lenticular hills; "drumlins," &c.; also, classes of assorted drift: Orange sands, osars, kames, &c.; valley drift; moraine headed gravel trains; loess tracts; and lake basin deposits. Refers to speculations respecting origin of glacial epoch.

—— [Report of division of Quaternary geology.]

Fifth Annual Report of the U. S. Geol. Survey, 1883-'84, pp. 20-24.

Calls attention to some drift phenomena in Iowa, Nebraska, and Dakota.

—— The requisite and qualifying conditions of artesian wells.

Fifth Annual Report of the U. S. Geol. Survey, 1883-'84, pp. 125-127.

Contains a discussion of the geologic elements affecting the success of artesian wells.

CHANCE (H. M.). The anticlinal theory of natural gas.

Am. Inst. Mining Eng. Trans. vol. 15, p. 11.

CHAPMAN (E. J.). On the Wallbridge hematite mine, as illustrating the stock-formed mode of occurrence of certain ore deposits.

Roy. Soc. Canada, Proc. vol. 3, Section IV, pp. 23-26.

CHAPMAN (E. J.)—Continued.

Describes the crystalline rocks of the district; discusses the nature of some of the beds and the time of extrusion of the red syenites, which are thought to have been introduced in molten condition.

CHAUVENET (W. M.). Notes on the samples of iron ore collected in Alabama.

Tenth Census: Report on the Mining Industries of the United States, pp. 383-399.

Occasional items of geologic information.

—— Notes on the samples of iron ore collected in Kentucky.

Tenth Census: Report on the Mining Industries of the United States, pp. 289-300 and map.

Description of geologic features of some of the mines.

—— Notes on the samples of iron ore collected in Missouri.

Tenth Census: Report on the Mining Industries of the United States, pp. 403-420.

Geologic description of the deposits.

—— Notes on the samples of iron ore collected in Tennessee.

Tenth Census: Report on the Mining Industries of the United States, pp. 351-365.

Description of geologic features at some of the mines.

Chesapeake Bay, geology at head of, McGEE.

CHESTER (Frederick D.). Results from a study of the gabbros and associated amphibolites in Delaware.

Am. Ass. Adv. Sci. Proc. vol. 34, pp. 215-216.

Supposes the gabbro to have been intruded between gneisses of the Philadelphia belt. Describes its petrography and distribution and also that of the associated amphibolites and gabbro-diorites. Discusses the cause and effect of foliation and of paramorphic changes.

Cincinnati, geology of, JAMES.

CLARKE (F. W.). Report of work done in the division of chemistry and physics, 1884-'85.

U. S. Geol. Survey Bulletin No. 27, vol. 4, pp. 531-610.

Gives analyses of fayalite from Yellowstone Park; serpentine from Newburyport, Mass.; hornblende-andesite from Bogusloff Island; eruptive rocks from New Mexico; dacite and rhyolite from Washoe, Nev.; sandstone from Ohio and from Stony Point, Mich.; limestone from Randolph County, Va.; and coals and

CLARKE (F. W.)—Continued.
minerals from various localities. The analyses were made by Clarke, Gooch, Chatard, Whitfield, and Riggs.

CLARKE (J. M.). A brief outline of the geological succession in Ontario County, New York, p. 14, map, 8°.

Assembly Document No. 16, Albany, 1886. Not seen.

CLAYPOLE (E. W.). Buffalo and Chicago, or "What might have been."

[Read to the American Association for the Advancement of Science, 1886.]
Am. Nat. vol. 20, pp. 856–862.
Abstract in Am. Ass. Adv. Sci. Proc. vol. 35, p. 224.
Discusses the effect of slight causes upon the drainage of the great lakes and the glacial outlet near Chicago. Thinks that the subsidence of the St. Lawrence region was sufficient to necessitate the present drainage, but that it was more probably due to a glacial ice dam in the Straits of Mackinaw during the retreat of the glacier.

—— The old gorge at Niagara.

Science, vol. 8, p. 236.
Discusses early drainage of the district and announces discovery of ledges of limestone in the valley from the whirlpool.

Clinton group, Alabama, Georgia, and Tennessee, PORTER.
of Ohio, FOERSTE.

Coal, Alabama, Georgia, and Tennessee, PORTER.
anthracite region of Pennsylvania, ASHBURNER.
Arkansas, HARVEY.
Colorado, HILLS.
field, Ohio, ORTON.
field, Pittsburgh, D'INVILLIERS, LESLEY.
field, Warrior, Alabama, MCCALLEY.
Mexico, COPE.
Montana, DAVIS, ELDRIDGE.
of Northwest Canada, KINAHAN.
of the Northwest, PUMPELLY.
of the United States, PRIME.
Ohio, characteristics of, ORTON.
origin, LESQUEREUX.
Raccoon field, Alabama, GIBSON.
Rocky Mountains in Canada, DAWSON, MERRITT.
Sydney, N. S., ROUTLEDGE.
Tipton Run, Pa., ASHBURNER.
Washington Territory, WILLIS

Colorado, cañon, PRESTWICH.
coal, HILLS.
conglomerate beds of Jefferson Co., CROSS.
extinct geyser basin, COMSTOCK.
observations in, VOM RATH.
rhyolite, CROSS.
San Juan Mountains, COMSTOCK.
trip to Telluride, San Miguel Co., VAN DIEST.
veins and geology of Southwestern, COMSTOCK.

COMSTOCK (Theodore B.). A remarkable extinct geyser basin in Southwestern Colorado.

[Read to American Association, 1886.]
Am. Nat. vol. 20, pp. 963–965. Abstract in Am. Ass. Adv. Sci. Proc. vol. 35, p. 232.
Briefly describes mounds and other evidences of former geyser action.

—— Peculiarities of the drift of the Rocky Mountains.

Abstract in Am. Nat. Nov. 1886, and brief notice in Am. Assoc. Adv. Sci. Proc. vol. 35, p. 233.
Discussion of results of glacial action, characteristics of the drift, and relation of timber line to glaciation.

—— The geology and vein structure of Southwestern Colorado.

Am. Inst. Mining Eng. Trans. vol. 15, p. 48 and map.
After a description of the topography, the general geology of the district is described and the age and relations of the various formations are discussed, from the Archean to the volcanic and drift. The source of the volcanic rocks and the order and means of their extrusion and their relation to the veins are reviewed in detail and an account is given of the veins and their mineral contents. The paper is accompanied by a geologic map and two topographic maps.

—— The veins of Southwestern Colorado.

[Read to American Association, 1886.]
Am. Nat. vol. 20, pp. 1043–1044.
Supposes the vein history of the San Juan district to have commenced at the close of the Cretaceous. Discusses briefly the sequence of lava flows, dislocations, and vein formation.

Connecticut, cutting of gorges in trap ridges, EMERSON.
iron ore mines, PUTNAM.
trap and sandstone at Tariffville, RICE.
Trias of, DAVIS.

Continents and ocean basins, LE CONTE.

COOK (George H.). Geological survey of New Jersey, annual report of the State geologist for the year 1885, pp. 228, 8°, Trenton, 1885.

Administrative report; introductory remarks to papers on geology by Britton and by F. J. H. Merrill; account of mining operations; paper on water supply from artesian and other bored wells in New Jersey; drainage; forestry; history of the geological surveys in New Jersey; and discussion of methods of topographic survey.

—— Sketch of the geology of the Cretaceous and Tertiary formations of New Jersey.

In Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by R. P. Whitfield, U. S. Geol. Survey, Monograph No. 9, pp. ix-xiii and map in pocket. (Also published by New Jersey Geological Survey.)

Describes and shows the areal distribution, structure, and stratigraphy of the formations. Discusses the age of the post-Cretaceous formations of Southern New Jersey.

[**COPE** (E. D.).] [On the recent earthquake.]

Am. Nat. vol. 20, pp. 869-870.

Discusses the cause and calls attention to a fault along the fall line of the Atlantic seaboard.

—— Report on the coal deposits near Zacualtipan, in the State of Hidalgo, Mexico.

Am. Phil. Soc. Proc. vol. 23, pp. 146-151.

Describes the geology of the coal bearing Cretaceous beds and the associated trap rocks.

CORNING (Frederick G.). The gold deposits of the Tipuani River, Bolivia, S. A.

Eng. and Mining Journal, vol. 42, pp. 58-60.

Describes the gravels and the rocks upon which they lie.

CRAGIN (F. W.). Further notes on the Dakota gypsum of Kansas.

Washburn Coll. Lab. Bulletin, vol. 1, pp. 166-168.

Discusses its stratigraphic position and genesis. Describes new localities.

CRANDALL (A. R.). The occurrence of trap rocks in Eastern Kentucky.

Am. Ass. Adv. Sci. Proc. vol. 34, pp. 236-237.

Describes dike in Carboniferous of Elliott County. (See also paper on same by J. S. Diller.)

Cretaceous, California, BECKER, LE CONTE.
coal of Northwest Canada, KINAHAN.
coal of Rocky Mountains, MERRITT.
fauna of New Jersey, WHITFIELD.
flora of North America, NEWBERRY.
floras of the Northwest, DAWSON.
Montana, HAYDEN.
Nebraska, HICKS.
New Jersey, COOK.
Staten Island, N. Y., BRITTON.
Texas, HILL.

CROSBY (Wm. O.). Common minerals and rocks, pp. 205, 12°, Boston, 1886.

[Guides for Science Teaching.]

—— Notes on joint structure.

Boston Soc. Nat. Hist. Proc. 1885, pp. 243-248.

Discusses previous views on joint structure. Describes joints in Miocene sediments on Potomac River and in felsite at Needham, Mass.

CROSS (Whitman). On the occurrence of topaz and garnet in lithophyses of rhyolite.

[Read to Colorado Scientific Society.]

Am. Jour. Sci. III, vol. 31, pp. 432-438.

Describes mode of occurrence and petrography of the rhyolite.

—— and **EAKINS** (L. G.). On ptilolite, a new mineral.

Am. Jour. Sci. III, vol. 32, pp. 117-121.

[Read before the Colorado Scientific Society, May, 1886.]

Incidentally describes some features of the conglomerate beds of Jefferson County, Colorado, and the andesite pebbles of which it is chiefly composed.

CROZIER (A. A.). Evidences of glacial action on the shores of Lake Superior.

Science, vol. 7, p. 145.

Calls attention to glacial grooves and scratches about Peninsula Harbor and terrace on Verte Island in Nipigon Bay.

D.

Dakota, drift, CHAMBERLIN.

DALE (T. Nelson). New England Upper Silurian.

Canadian Inst. Proc. vol. 22, pp. 69-70.

Describes the metamorphosed Helderberg rocks at Bernardston, Mass., and Littleton, N. H.

DANA (James D.). A dissected volcanic mountain; some of its revelations.

Am. Jour. Sci. III, vol. 32, pp. 247-255.

Describes the Island of Tahiti, its topography and erosion, and the structure of its lava flows and volcanoes.

—— On the Lower Silurian fossils from a limestone of the original Taconic of Emmons.

[Read to American Association, 1885.]

Am. Jour. Sci. III, vol. 31, pp. 241-248.

Briefly reviews Emmons's Taconic theories and calls attention to the danger of correlating formations by lithologic analogies. Describes the occurrence of fossils at Canaan in the "Sparry" limestones of Emmons, in the same general vicinity near the overlying slates, and also in detached masses of limestone. Traces the same limestone belt northward across Massachusetts into Vermont.

—— [On volcanic eruption.]

Am. Jour. Sci. III, vol. 31, pp. 395-397.

—— The history of Taconic investigation previous to the work of Professor Emmons.

[Opening part of address to Berkshire Historical Society.]

Am. Jour. Sci. III, vol. 31, pp. 399-400.

Describes Eaton and Dewey's geologic studies in the Taconic district.

—— The Taconic stratigraphy and fossils.

Am. Jour. Sci. III, vol. 32, pp. 236-239.

Gives a brief résumé of the stratigraphy and structure of the Taconic district. Discusses the possibility of superposition by overthrust, with negative conclusion. Calls attention to increase of the amount of metamorphism eastward and to its effects upon organic remains.

[——] Geologic age of the North Atlantic oceanic basin and origin of Eastern American sediments.

Am. Jour. Sci. III, vol. 32, pp. 407-408.

Describes the derivation of the American Paleozoic from the Archean border in opposition to Hull's idea of their origination from the district now covered by the Atlantic.

DARTON (Nelson H.). [Notes on the formations associated with the Green Pond Mountain series and on the geology of Orange County, New York.]

Mineral Physiology and Physiography, by T. Sterry Hunt, p. 591.

Calls attention to the occurrence of Upper Silurian limestones at Upper Longwood and Newfoundland, N. J., and to some points in the geology of Orange County.

—— On the area of Upper Silurian rocks near Cornwall Station, Eastern-Central Orange County, New York.

Am. Jour. Sci. III, vol. 31, pp. 209-216.

Describes Lower Helderberg limestones and underlying conglomerate, forming an outlier far from the main mass of the formation; the Water Lime, Pentamerus, and Delthyris Shale being recognized, the last by finely preserved fossils of many species, some peculiarities of which are described.

—— The Taconic controversy in a nutshell.

Science, vol. 7, pp. 78-79.

Calls attention to the significance of his discovery, and that of Dale and others, of the occurrence of Trenton fossils in the slates of Orange County, N. Y.

Davenport, Iowa, geology, BARRIS.

DAVIS (William M.). The structure of the Triassic formation of the Connecticut Valley.

Am. Jour. Sci. III, vol. 32, pp. 342-352.

Abstract in Am. Ass. Adv. Sci. Proc. vol. 35, pp. 224-227.

Discusses the Triassic monoclines and the means by which they were effected. Calls attention to the presence of strike faults in Connecticut and Massachusetts and describes the structure of Toket and Pond Mountains as an instance. Discusses the possible extension of the Trias over the area now separating the New Jersey and Connecticut districts and the mode of separation. Discusses faulting in general and advances a hypothesis to account for the monoclinal structure and the many observed faults. Presents some evidence upon which the hypothesis is based.

—— Relation of the coal of Montana to the older rocks.

Tenth Census: Report on the Mining Industries of the United States, pp. 697-737.

DAVIS (W. M.)—Continued.

Detailed geologic description of an area of about 10,000 square miles in South-Central Montana. Lists of fossils by Whitfield and description of eruptive rocks by Lindgren.

DAWSON (George M.). Preliminary report on the physical and geological features of that portion of the Rocky Mountains between lat. 49° and 50° 30′.

Annual Report of the Geol. Survey of Canada, vol. 1, n. s. B, pp. 167 and map.

Account of previous explorations and reports. Description of physiography, flora, and the distribution, stratigraphy, structure, and relations of the geologic formations. The paper is illustrated by plates from photographs, a colored map, and sections of the Cascade coal district and of a portion of the Rocky Mountains.

DAWSON (*Sir* William). Cretaceous floras of the Northwest.

Canadian Rec. Sci. vol. 2, pp. 1–2.

Discusses horizon of the Kootanic and of the other groups and the climate and floral conditions at the time of their deposition.

—— Geology of the Atlantic Ocean.

[Address to British Association, September, 1886.]

Canadian Rec. Sci. vol. 30, pp. 201–228 and 265–285. Also in Popular Science Monthly, vol, 30, pp. 41–51, 184–194, and Sci. Amer. Supt. vol. 22, pp. 9020–9023.

Discusses the Appalachian flexures and the derivation of the materials of the formations of the Eastern United States.

—— Note on bowlder drift and sea margins at Little Metis, Lower St. Lawrence.

Canadian Rec. Sci. vol. 2, pp. 36–38.

Describes the beaches and terraces and discusses their origin.

—— On the Mesozoic floras of the Rocky Mountain region of Canada.

Roy. Soc. Canada, Trans. vol. 3, Sec. IV, pp. 1–22 and pl.

Includes a brief description of the formations, their horizon, structure, and history, by G. M. Dawson. Discusses the geologic relation of the floras.

Delaware, gabbros &c., CHESTER.

Devonian, Chemung section, Bradford County, Pa., LILLEY.
classification of Upper, WILLIAMS.
Oriskany in Lycoming County, Pa., WOOLMAN.
revision of Cayuga Lake section, N. Y., WILLIAMS.
Tully Limestone, WILLIAMS.

DILLER (J. S.). Notes on the geology of Northern California.

U. S. Geol. Survey Bulletin No. 33, vol. 5, pp. 369–387.

Describes the carboniferous limestones, the structure of the Sierra Nevada, and the general distribution of the metamorphic, volcanic, and cretaceous rocks. Discusses the age of the faulting of the Sierra Nevada, the age of the auriferous slates, and the relation of the Sierra, Coast, and Cascade Ranges.

—— Notes on the peridotite of Elliott County, Kentucky.

Am. Jour. Sci. III, vol. 32, pp. 121–125.

Describes the petrographic nature of the dikes in the carboniferous sandstones and shales in Eastern Kentucky and discusses their relations to the strata, arriving at the conclusion that the peridotite has been intruded into its present position.

Dinocerata, MARSH.

D'INVILLIERS (E. V.). Preliminary report of work done in 1885 on the resurvey of the Pittsburgh coal region.

Annual Report of the Geol. Survey of Pa. for 1885, pp. 125–221 and pl.

Lists of elevations, description of geologic structure and of the Pittsburgh and associated coal beds and rocks.

—— The Cornwall iron ore mines, Lebanon County, Pa.

Am. Inst. Mining Eng. Trans. pp. 32 and map.

Describes the geology and structure of the district; the trap rocks and their relations to the shales and limestones. The paper is accompanied by a map and geologic sections.

—— See, also, **Lesley** (J. P.) and **D'Invilliers** (E. V.).

District of Columbia, geology of, McGEE.

Drift. See **Quaternary.**

DRUMMOND (A. T.). Our northwest prairies; their origin and their forests.

Canadian Rec. Sci. vol. 2, pp. 145–153.

Describes some features of the drift deposits and discusses the effect of glacial action.

DWIGHT (William B.). Recent explorations in the Wappinger Valley limestone of Dutchess County, N. Y., No. 5. Discovery of fossiliferous Potsdam strata at Poughkeepsie, N.Y.

[Read to American Association.]

Am. Jour. Sci. III, vol. 31, pp. 125–133 and pl. VI.

DWIGHT (W. B.)—Continued.

Abstract in Am. Ass. Adv. Sci. Proc. vol. 34, pp. 204–209.

Describes lithology and stratigraphy of the district in which Hudson River, Calciferous, Trenton, and Potsdam are associated. All are fossiliferous. Finds a fault bringing first and and last in contact and traces it to the Hudson near Clinton Point post office. Gives a map of district and section showing relations at fault line.

DWIGHT (W. B.)—Continued.

—— The peculiar structure of Clark's clay beds near Newburgh, N. Y.

Vassar Brothers Inst. Trans. vol. 3, pp. 86–97. Describes the clays of the Hudson Valley. Gives an account and figures of clay filled pot-holes in faulted block of sand near Clark's Dock Station.

—— See, also, **Ford** (S. F.) and **Dwight** (W. B.).

E.

EAKINS (L. G.). See **Cross** (Whitman).

Earthquakes, COPE, NEWBERRY, POWELL.

ELDRIDGE (George H.). Montana coal fields.

Tenth Census: Report on the Mining Industries of the United States, pp. 739–759.

Detailed descriptions of the various coal beds and the structural and stratigraphic relations of the associated formations.

ELLS (R. W.). On the geological formations of Eastern Albert and Westmoreland Counties, N. B., and of portions of Cumberland and Colchester Counties, N. S.

Annual Report of the Geol. Survey of Canada, vol. 1, n. s. E, p. 66 and map.

Issued separately in 1885.

EMERSON (B. K.). Holyoke trap range.

[Read to American Association, 1886.]

Brief abstracts in Am. Jour. Sci. III, vol. 32, pp. 323–324, and Am. Ass. Adv. Sci. Proc. vol. 35, pp. 233–234.

EMERSON (B. K.)—Continued.

Describes structure, volcanic phenomena, and petrography of the district.

—— Preliminary note on the succession of the crystalline rocks and their various degrees of metamorphism in the Connecticut River region.

Am. Ass. Adv. Sci. Proc. vol. 35, p. 231.

"A comparison of the Bernardston fossiliferous section with the successive bands of the same series eastward where the metamorphism gradually increases."

—— The age and cause of the gorges cut through the trap ridges by the Connecticut and its tributaries.

Am. Ass. Adv. Sci. Proc. vol. 35, p. 232.

"The gorges were cut by the preglacial drainage and the streams were restored to their old course by the position of their deltas."

EMMONS (S. F.). The genesis of certain ore deposits.

Am. Inst. Mining Eng. Trans. pp. 22, 1886.

Erosion, KING.

F.

FALDING (F. J.). Notes on Canadian fluor-apatite or fluor-phosphate of lime.

Eng. and Mining Jour. vol. 42, pp. 383–384, 403–404.

Describes some features of the rocks in which the mineral occurs.

Fault and fall line of Atlantic coastal plain, COPE.

Fire clay, Wellersburg, Pa., LESLEY, HARDEN.

Florida, Nummellite limestone, HEILPRIN.

Florida—Continued.

west coast geology, HEILPRIN.

geology of, KOST.

FOERSTE (Aug. F.). The Clinton group of Ohio, with descriptions of new species.

Scientific lab. of Denison Univ. Bulletin No. 1, pp. 63–120 and pls. 13–14.

Describes structural and stratigraphic relations of the Clinton and Niagara at many localities and along several section lines.

FORD (S. W.) and **DWIGHT** (W. B.). Preliminary report upon the fossils obtained in 1885 from metamorphic limestones of the Taconic series of Emmons, at Canaan, N. Y.

Am. Jour. Sci. III, vol. 31, pp. 248-255 and pl. VII.

Description of the limestone outcrop from which the fossils were obtained.

FRAZER (Persifor). Sketch of the geology of York County, Pennsylvania.

Am. Phil. Soc. Proc. vol. 23, pp. 391-410 and map.

Gives a brief description of the formations and discusses their stratigraphic and structural relations and their equivalency and horizon.

FRAZER (P.)—Continued.

Reviews the portion of Wadsworth and Whitney's Azoic system as applied to Southeastern Pennsylvania. The paper is accompanied by a map colored in accordance with the proposed scheme of the International Congress.

—— The work of the International Congress of Geologists and of its committees, pp. 109 and pl. 8°, 1886.

FREEMAN (H. C.). The geologic distribution of natural gas.

Am. Inst. Mining Eng. Trans. Oct. 1886, pp. 3.

Discusses occurrence of gas and geologic relations of La Salle County and adjacent parts of Illinois and adjoining States.

G.

Gas,
anticlinal theory of, CHANCE, WHITE.
distribution in United States, ASHBURNER.
geologic distribution, FREEMAN.
in Ohio, ORTON.
See, also, **Oil.**

GEIKIE (Archibald). Class book of geology, 18+516 pp. 12°, London, 1886.

Not seen.

GEIKIE (James). Outlines of geology, pp. 484, 8°, London, 1886.

Occasional references to well known American geologic features.

Geological surveys, GILBERT.

Georgia, iron ore and coal, PORTER.

GIBSON (A. M.). Report on the Raccoon Mountain coal field.

Report on the Warrior coal field, Alabama Geological Survey, pp. 544-555.

Describes topography, stratigraphy, and structure of the district.

GILBERT (Grove Karl). An account of some new geologic wrinkles.

[Read to American Association, 1886.]

Brief abstract in Am. Jour. Sci. III, vol. 32, p. 324, and Am. Ass. Adv. Sci. Proc. vol. 35, p. 227.

Describes small, postglacial anticlines in horizontal limestones of Western New York and discusses their cause.

[——] Geological survey of the United States: geology and explorations.

Appletons' Annual Cyclopædia for 1885, pp. 401-408.

GILBERT (G. K.)—Continued.

—— Inculcation of scientific method by example.

[Address to American Society of Naturalists.]
Am. Jour. Sci. III, vol. 31, pp. 284-299, 1 pl.

Discusses the causes of deformation of basin of Lake Bonneville.

—— [Report of the division of the Great Basin.]

Fifth Annual Report of the U. S. Geological Survey, 1883-'84, pp. 30-34.

Refers to the deformation of the basin of Lake Bonneville.

—— The place of Niagara Falls in geologic history.

Abstract in Am. Ass. Adv. Sci. Proc. vol. 35, pp. 222-223, and brief abstract in Am. Jour. Sci. III, vol. 32, pp. 322-323, and Science, vol. 8, p. 205.

Discusses the tilting of the shore lines of Lakes Ontario and Erie and their glacial outlets, the birth of the Niagara River, and the rate and amount of recession of the falls.

—— The topographic features of lake shores.

Fifth Annual Report of the U. S. Geological Survey, 1883-'84, pp. 69-123.

Discusses the formation of lake shores and their topography, illustrated by the ancient lakes of the Great Basin and Lakes Superior and Michigan. Contrasts the topographic results of fluvial, glacial, and littoral deposits.

GILPIN (Edwin). The geology of Cape Breton Island, Nova Scotia.

Geol. Soc. Quart. Jour. vol. 42, pp. 515-526 and pl.

GILPIN (E.)—Continued.

Describes the various formations and their relation and structure. The paper is accompanied by a geologic map.

—— The Nova Scotia gold mines.

Am. Inst. Mining Eng. Trans. vol. 14, pp. 674-688 and map.

Discusses the age and genesis of the gold bearing rocks and describes their structure and relations to associated formations. The paper is accompanied by a geologic map of the southern half of Nova Scotia.

Glaciers, RUSSELL, ALLEN.

GRANT (C. E.). Notes on Pleistocene fossils from Anticosti.

Canadian Rec. Sci. vol. 2, pp. 44-46.

Describes some features of the clay beds in which the fossils occur and calls attention to an apparent rising of the island.

GRATACAP (L. P.). Fish remains and tracks in the Triassic rocks at Weehawken, N. J.

Am. Nat. vol. 20, pp. 243-246.

Incidentally describes the shales and sandstones at the trap contact.

H.

HAGUE (Arnold) and **IDDINGS** (Joseph P.). Notes on the volcanic rocks of the Republic of Salvador, Central America.

Am. Jour. Sci. III, vol. 32, pp. 26-31.

Describes some interesting rocks, including basalt, pyroxene-andesite, hornblende-pyroxene-andesite, hornblende-mica-andesite, dacite, and possibly rhyolite. Discusses their relation to rocks of the Sierra Nevada and Great Basin of the United States.

HARDEN (E. B.). Report on fire clay of Wellersburg coal basin.

Annual Report of the Geol. Survey of Pa. for 1885, pp. 239-249.

Description of the clay bed and its geologic relations and structure.

HARVEY (F. L.). On Anthracomartus trilobitus Scud.

Phila. Acad. Nat. Sci. Proc. vol. 16, pp. 231-232.

Incidentally describes some features of the coal fields of Northern Arkansas.

—— The minerals and rocks of Arkansas, pp. 32, 8°, Philadelphia, 1886.

Gives a general review of Arkansas geology and references to localities of rocks.

HAYDEN (Ferdinand Vandeveer). [Report on geologic studies in Montana.]

Fifth Annual Report of the U. S. Geological Survey, 1883-'84, pp. 28-30.

Notes outcrops of Cretaceous and Laramie in district studied.

HEILPRIN (Angelo). Explorations on the western coast of Florida and in the Okeechobee wilderness, with special reference to the geology and zoölogy, pp. 127 and pls. 8°, Philadelphia, 1886.

Pages 1-64 and plates not yet issued.

HEILPRIN (A.)—Continued.

Presents general summary and conclusions in regard to the geology of Florida on pp. 65-67 and gives a table showing the relations of the Atlantic and Gulf Tertiaries of the United States, pp. 127.

—— Notes on the Tertiary geology and paleontology of the Southern United States.

Phila. Acad. Nat. Sci. Proc. vol. 16, pp. 57-58.

Recognizes, from fossils, beds of Clairbornian horizon in San Augustine County, Texas; the Nummulitic near Gainesville, Fla.; and the Lower Eocene in Kentucky near Paducah.

HICKS (L. E.). Some typical well sections in Nebraska.

Am. Ass. Adv. Sci. Proc. vol. 35, pp. 217-219.

Graphic sections from the Brownville, Lincoln, and St. Helena wells, with explanatory notes.

—— The Dakota group south of the Platte River in Nebraska.

Am. Ass. Adv. Sci. Proc. vol. 34, pp. 217-219.

Describes the stratigraphy, structure, fossils, and topography of the group and details of its unconformable deposition on the Permo-Carboniferous.

—— The Lincoln salt basin.

Am. Ass. Adv. Sci. Proc. vol. 35, p. 219.

Considers the salt basin the remnant of a Cretaceous sea border.

—— The Permian in Nebraska.

Am. Nat. vol. 20. pp. 881-883. Abstract in Am. Ass. Adv. Sci. Proc. vol. 35, pp. 216-217.

Considers the calcareous beds in the valley of Blue River, Gage County, of Permian age. They may be unconformable to the under-

HICKS (L. E.)—Continued.

lying Coal Measures and their contact with the overlying Cretaceous shows unconformity by erosion. About 10 per cent. of the fossils carboniferous. Thickness unknown. Discussed by Newberry, Walcott, Davis, Claypole, and H. S. Williams in Am. Jour. Sci. III, vol. 32, pp. 321–322.

HILGARD (E. W.). Dr. Otto Meyer and the Southwestern Tertiary.

Science, vol. 7, p. 11.

Discusses Meyer's theory that the Grand Gulf group overlies the Vicksburg group.

HILL (Frank A.). Description of the Wyoming Buried Valley between Pittston and Kingston.

Annual Report of the Geol. Survey of Pa. for 1885, pp. 637–647.

Description of drift deposits and evidence from bore holes.

HILL (Robert T.). Salient geologic features of Travis County, Texas.

Austin Statesman, December 15, 1886.

Describes topography and the subdivisions of the Cretaceous of the district.

HILLS (R. C.). Remarks on the occurrence of coal in the Carboniferous formation at Aspen and Greenwood Springs, Colorado.

Colorado Sci. Soc. Proc. vol. 2, pp. 25–26.

Describes thin seam of impure bituminous coal in Middle Carboniferous.

HITCHCOCK (C. H.). Geological map of the United States and part of Canada. Compiled to illustrate the scheme of coloration and nomenclature recommended by the International Geological Congress.

Am. Inst. Mining Eng. Trans. map 17 by 27 inches, explanation, pp. 24, 1886.

On the map there are left uncolored areas in California, Nevada, Idaho, and Utah. With some exceptions, the information on McGee's map is incorporated. In the explanation, previous maps are described and attention is called to the differences between them. The sources of information are given, as well as reasons for changes in the present map.

HONEYMAN (D.). Geology of Cornwallis or McNab's Island, Halifax Harbor.

Roy. Soc. Canada Trans. vol. 3, sec. 4, p. 27.

Describes the drift deposit.

HOOKER (W. A.). Notes on mining in Oaxaca.

Am. Inst. Mining Eng. Trans. pp. 8.

Briefly describes some of the geologic features of the district.

HOUTHUMB (C. A.). Aus den Oelregionen Pennsylvaniens.

Fels zum Meer, July, 1886.

HOVEY (H. C.). Niagara River, gorge and falls.

Sci. Am. Supt. vol. 22, No. 538, p. 8917.

Gives a summary of the discussion on the subject before the American Association and discusses some of the evidence.

HOWE (James Lewis). Lithographic stone from Tennessee.

Elisha Mitchell Sci. Soc. Jour. 1885–'86, pp. 144–145.

Gives analyses.

Hudson Bay district, BELL.

HULL (Edward). The geological age of the North Atlantic Ocean.

Nature, vol. 34, p. 496.

Discusses the source of the material of some of the American Paleozoic formations.

HUNT (T. Sterry). Mineral physiology and physiography. A second series of chemical and geological essays. 17, 710 pp. 8°, Boston, 1886.

Besides reprints of former papers, discusses the genetic history of crystalline rocks, the history of the pre-Cambrian rocks, and the Taconic question. Discusses recent information in regard to the rocks at the head of the Bay of Fundy, the Lake Superior district (pp. 579, 611, and 621), the Cambrian of Utah (p. 623) and of the Grand Cañon (p. 624), Texas (p. 624) and of the Taconic region (pp. 627, 629, 643, 645, and 647). On p. 591 has notes by Darton on the Green-Pond Mountain series and associated formations.

I.

Idaho, Pliocene sands, MERRILL.

IDDINGS (Joseph P.). The columnar structure in the igneous rock on Orange Mountain, New Jersey.

[Read to Philosophical Society of Washington.]

IDDINGS (J. P.)—Continued.

Am. Jour. Sci. III, vol. 31, pp. 321–331 and plate ix.

Abstract in Washington Phil. Soc. Bull. 8, pp. 19–24.

Describes exposure in which very perfect, large columns are capped by smaller ones with

IDDINGS (J. P.)—Continued.

radial structure, the plate showing the relations. Concludes that both belong to the same flow. Discusses cause of columnar structure. Describes microscopic character of the rock and considers the sheet a lava flow rather than intrusive.

—— See, also, **Hague** (Arnold).

Illinois, Quaternary, WORTHEN.
 gas, FREEMAN.

Indiana, geologic map, BRANNER.

Iowa, drift, CHAMBERLIN.
 Davenport, geology, BARRIS.
 movement of glaciers, IRISH.

IRISH (C. W.). Movement of the glaciers of the ice period in Iowa and its vicinity.

Iowa Hist. Record, vol. 1, pp. 162-185.

Describes many features of the topography, drainage, and drift deposits.

Iron ore, Alabama, CHAUVENET.
 Alabama, Georgia, and Tennessee, PORTER.
 and schists of Northwest, IRVING, VAN HISE.
 Connecticut and Massachusetts mines, PUTNAM.
 Cornwall mines, Pennsylvania, D'INVILLIERS, LESLEY, WILLIS.
 distribution in United States, PUMPELLY.
 district of the Upper Mississippi, WILLIS.
 Kentucky mines, CHAUVENET.
 magnetites of Eastern Pennsylvania, WILLIS.
 Maryland, BENTON.
 Michigan and Northern Wisconsin, PUTNAM, WILLIS.
 Missouri, CHAUVENET.
 New Jersey, PUTNAM.

Iron—Continued.
 New York, PUTNAM.
 Northern New England, BENTON.
 North Carolina, WILLIS.
 Ohio, WILLIS.
 Pennsylvania, PUTNAM, WILLIS.
 pyrites, deposits of the Alleghanies, WENDT.
 Tennessee, CHAUVENET, WILLIS.
 Tilly Foster mine, RUTTMAN.
 United States, VOGDES, PUMPELLY.
 Virginia, CHAUVENET.
 Wallbridge, Canada, CHAPMAN.
 west of the one hundredth meridian, PUTNAM.
 Wyoming, AUGHEY.

IRVING (R. D.). Origin of the ferruginous schists and iron ores of the Lake Superior region.

Am. Jour. Sci. III, vol. 32, pp. 255-272.

Discusses the various theories and the general question of metamorphism. Describes the general features and petrography of the iron bearing formations of the region and deduces therefrom a theory to account for the origin of the ores.

—— Preliminary paper on an investigation of the Archean formations of the Northwestern States.

Fifth Annual Report of the U. S. Geological Survey, 1883-'84, pp. 175-242 and pl.

Gives a general account of the problems to be attacked, a description of areas of Huronian and supposed Huronian age, and a preliminary geologic map. Describes the petrography and discusses the evidence of enlargements of mineral fragments in certain detrital rocks of the region, and metamorphism in the Huronian.

—— Törnebohm on the formation of quartzite by enlargement of the ouartz fragments of sandstone.

Am. Jour. Sci. III, vol. 31, pp. 225-226

J.

JAMES (Joseph F.). The geology of Cincinnati.

Cincinnati Soc. Nat. Hist. Jour. vol. 9, pp. 20-31, 136-141.

Describes the rock formations and drift terraces.

Joint structure, CROSBY.

JUKES-BROWN (A. J.). The student's hand book of historical geology, pp. 12, 597, 12°, New York, 1886.

Not seen.

JULIEN (A. A.). [Remarks on the thin bedded gneiss border of the Adirondack region.]

N. Y. Acad. Sci. Trans. vol. 5, p. 72.

K.

Kansas, notes on gypsum deposits, CRAGIN.

Kaolin, Brandywine Summit, Delaware County, Pa., ASHBURNER.
Chester and Delaware County, Pa., LESLEY.

Kentucky, iron mines, CHAUVENET.
Lower Eocene, HEILPRIN.
trap rocks of Eastern, CRANDALL, DILLER.

KINAHAN (G. H.). Note on the coal deposits of the northwest territories of Canada.

Dublin Roy. Geol. Soc. Jour. vol. 6, pp. 275–287.
Not seen.

KING (F. H.). Internal chemical and mechanical erosion a factor in continent and mountain building.

Am. Nat. vol. 20, pp. 53–57.
Discusses the possibilities of underground chemical solution decreasing the strength and amount of solid matter in continents and the results.

KOST (J.). Geology of Florida.

Am. Ass. Adv. Sci. Proc. vol. 35, p. 231.
Brief abstract of general description.

KÜCH (R.). Petrographische Mittheilungen aus den südamericanischen Anden.

Neues Jahrbuch, Band I, pp. 35–48, 1886.
On rhombic pyroxene in andesites and its determination; describes quartz-pyroxene-andesite of Cumbal and dacite-pearlite from Loma de Ales and gives chemical analyses.

L.

Lake Bonneville, GILBERT.
Lake Lahontan, RUSSELL.
Lake shores, topography, GILBERT.
Lake Superior, glacial action on shores, CROSIER.
Lake Superior copper mines, WHEELER.

LAMPLUGH (G. W.). On glacial shell beds in British Columbia.

Geol. Soc. Quart. Jour. vol. 42, pp. 276–286.
Describes beds of Vancouver Island and in valley of Fraser River. Discusses time of deposition.

—— On ice grooved rock surfaces near Victoria, Vancouver Island; with notes on the glacial phenomena of the neighboring region and on the Muir glacier of Alaska.

Yorkshire Geol. and Poly. Soc. Proc. vol. 9, n. s. pp. 57–70.

LANGDON (D. W.). Observations on the Tertiary of Mississippi and Alabama, with description of new species

Am. Jour. Sci. III, vol. 31, pp. 202–209.
Describes sections along Pearl River from Jackson to Yazoo City; dips in the main southward. The Jackson beds underlie the Vicksburg and Orbitoides Limestone. The Alabama prairies supposed to be underlaid by Tuomey's White Limestone. Describes sections at St. Stephens Bluff, Bladen's Springs, near Enterprise, west of Meridian, and near Claiborne.

LAWSON (A. C.). On the geology of the Lake of the Woods region, with special reference to the Keewatin (Huronian ?) belt of the Archean rocks.

Annual Report of Geol. Survey of Canada vol. 1, n. s. CC, p. 141.
Issued separately in 1885.

—— Some instances of gneissic foliation and schistose cleavage in dikes and their bearing upon the problem of the origin of the Archean rocks.

Canadian Inst. Proc. vol. 32, pp. 115–128.
Discusses foliation and metamorphism. Describes and figures instances of foliation in dikes at various West Canadian localities.

LE CONTE (Joseph). A post-Tertiary elevation of the Sierra Nevada shown by the river beds.

[Presented to the National Academy of Sciences.]
Am. Jour. Sci. III, vol. 32, pp. 167–181.
Discusses the effect of orographic movements on drainage. Calls attention to some features of the history of Colorado and Mississippi Rivers. Describes river beds of parts of California. Discusses some structural features of the Great Basin, the relation of the post-Tertiary movements to the great lava flood and to the great fissures and normal faults of the West, the contemporaneous elevation of the west side of South America and subsidence of the

LE CONTE (J.)—Continued.

mid-Pacific bottom, and the cause of the movements. In conclusion, makes an estimate of the amount of elevation and erosion.

—— Compend of geology, 12°, New York, 1886.

—— On the permanence of continents and ocean basins, with special reference to the formation and development of the North American continent.

Geol. Mag. n. s. vol. 3, pp. 97-101.

Discusses relation of land and sea areas in Archean and in lower Silurian times and the source of sediments of the formations.

LESLEY (J. P.). Annual report of the geological survey of Pennsylvania for 1885, pp. 769, 18 pl. and atlas of maps, 8°, Harrisburg, 1886.

Administrative report and history of the survey. Geological papers by Carll, Lesquereux, D'Invilliers, Lesley, Ashburner, Linn, Linton, Harden, and Hill, and paper on the geodetic survey of the State by Merriman.

—— Dr. Orton's Ohio gas and oil report.

Science, vol. 8, pp. 233-235.

Discusses the formation of petroleum, cavernous limestones, underground drainage and erosion, and the cause and age of the Cincinnati uplift. Describes some features of difference between the geology of Pennsylvania and Ohio.

—— Some general considerations of the pressure, quantity, composition, and fuel value of rock gas or the natural gas of the oil regions of Pennsylvania.

Annual Report of the Geological Survey of Pa. for the year 1885, pp. 657-680.

Discusses movement of fragmental material of rocks due to underground erosion and porosity, the resulting pressure and its relation to the pressure under which oil and gas are found. Calls attention to areas of the State that are barren of oil and gas and to those likely to yield them.

—— Some general considerations respecting the origin and distribution of the Delaware and Chester kaolin deposits.

Annual Report of the Geol. Survey of Pa. for 1885, pp. 571-591 and map.

Discusses strike and linear extent of crystalline rocks of the district. Calls attention to parallelism of strike of kaolin and limestones, some of which are thought to be altered Lower Silurian. Advances the hypothesis that decomposition of gneisses &c. is greatly increased by solutions from adjacent limestones &c., and that this has been the cause of the deep decomposition at the Hoosac tunnel, in parts of the Southern Atlantic States, and elsewhere. Discusses the origin of kaolin, of the cretaceous clays of the coastal plain, and the relation of rock decay to structure, texture, and composition.

—— The coal beds and fire clays of the Wellersburg basin in Somerset County.

Annual Report of the Geol. Survey of Pa. for 1885, pp. 227-229.

Describes the geology and structure of the district and discusses the horizon of some of the beds.

—— The geology of the Pittsburgh coal region.

Am. Inst. Mining Eng. Trans. pp. 39.

Describes the coal beds of Western Pennsylvania and westward; discusses their former extent, the gap between the Carboniferous and Trias in Pennsylvania, the horizon and extension of various Carboniferous beds, the Devonian beds and oil sands, and the structure of bituminous district.

—— and **D'INVILLIERS** (E.V.). Report on Cornwall iron ore mines, Lebanon County.

Annual Report of the Geol. Survey of Pa. for 1885, pp. 491-570 and map.

Describes the geology in detail. Discusses the means and mode of intrusion of the trap, the relation of the ore beds and Mesozoic, the genesis of the ore, and the age and relations of the associated slates. In a supplementary note Lesley calls attention to the similarity of Cornwall and Dillsburg deposits. The paper is illustrated by heliotypes of outcrops and of two relief models, and by maps.

LESQUEREUX (Leo). On the vegetable origin of coal.

Annual Report of the Geol. Survey of Pa. for 1885, pp. 95-121.

Discussion of theories on the subject.

LEWIS (H. Carvill). Some examples of pressure fluxion in Pennsylvania.

British Ass. Rep. for 1885, pp. 1029-1030.

States his opinion that the belt of Laurentian rocks of Southeastern Pennsylvania are of eruptive origin, consisting of highly metamorphosed syenites, acid gabbros, trap granulites, &c.

—— Comparative studies upon the glaciation of North America, Great Britain, and Ireland.

[Read to British Association, Sept. 1886.]

Am. Nat. vol. 20, pp. 919-927, and Nature, vol. 35, pp. 89.

Refers to some well known phenomena of American glaciation.

LILLEY (A. T.). A revision of the section of Chemung rock exposed in the Gulf Brook gorge at Le Roy, Bradford County, Pennsylvania.

Am. Phil. Soc. Proc. vol. 23, pp. 291.

LINDGREN (Waldemar). Eruptive rocks [of Montana coal districts].

Tenth Census: Report on the Mining Industries of the United States, pp. 719-737.

General descriptions of the occurrence of the eruptive rocks of South-Central Montana and of their lithologic characters.

LINN (Alonzo) and **LINTON** (Edward). Notes on the mountain limestone (at the base of No. XI) in the Washington County gas wells.

Annual Report of the Geol. Survey of Pa. for 1885, pp. 222-226.

LINN (A.) and **LINTON** (E.)—Cont'd.

Description of lithology of the beds and their stratigraphic position. Supplementary note by J. P. Lesley on the stratigraphy and mode of deposition.

LINTON (Edward). See **LINN** (Alonzo).

Long Island, N. Y., geology, MERRILL.

LOW (A. P). On the Mistassini expedition.

Annual Report of the Geol. Survey of Canada, vol. 1, n. s. D, p. 46, and map.

Describes and maps distribution of Laurentian, Huronian, Cambrian, and superficial formations, giving an account of their general stratigraphy and structural relations.

Lower Silurian. See **Silurian**, Lower.

M.

McCALLEY (Henry). On the Warrior coal field.

Geological Survey of Alabama, pp. 571, 8°, 1886.

After a preliminary general description, the topography, stratigraphy, and structure of the coal counties are described in detail.

McCONNELL (R. G.). On the Cypress Hills, Wood Mountain, and adjacent country.

Annual Report of the Geol. Survey of Canada, vol. 1, n. s. C, p. 76 and two maps.

Issued separately in 1885.

McDOUGALL. Shells in sand at Selkirk.

Canadian Inst. Proc. vol. 21, p. 270.

Refers to their relation to the glacial drift.

McGEE (W J). Geography and topography of the head of Chesapeake Bay.

[Read to American Association, 1886.]

Brief abstract in Am. Jour. Sci. III, vol. 32, p. 323.

Describes the drainage and topographic features.

—— Map of the United States, exhibiting the present status of knowledge relating to the areal distribution of geologic groups. (Preliminary compilation.)

Fifth Annual Report of the U. S. Geological Survey, 1883-'84.

In pocket. Explanation, pp. 34-37. Map also published with legend in French.

The areas left uncolored are California, Oregon, the greater part of New Mexico, Washington Territory, Idaho, and Nevada, and a part of Arizona, Montana, and Texas.

McGEE (W J)—Continued.

—— [Notes on the geology of Washington and vicinity.]

Report of the Health Officer of the District of Columbia for 1884-'85, pp. 19-21, 23, 24, 25.

Describes the composition and distribution of the Columbia and the underlying Potomac formations and some features of the crystalline rocks.

Maine, geology of Cobscook Bay, SHALER.
wind action, STONE.

MARCOU (Jules). On two plates of stratigraphical sections of the Taconic ranges, by James Hall.

Science, vol. 7, pp. 393-394.

Calls attention to the extensive distribution of the sections referred to.

MARSH (O. C.). The gigantic mammals of the order Dinocerata.

Fifth Annual Report of the U. S. Geological Survey, 1883-'84, pp. 243-302.

Describes the Eocene deposits of Wyoming in which the remains are found and gives a brief review of the Tertiary geology of the West.

MARTIN (D. S.). [Remarks on the tide water gneisses.]

N. Y. Acad. Sci. Trans. vol. 5, pp. 19-20.

Calls attention to the lithologic differences between the gneisses of the highlands of New Jersey and New York and those of Manhattan Island, Philadelphia, &c.

Maryland, Chesapeake Bay, head of, McGEE.
gabbros &c. near Baltimore, WILLIAMS.
iron mines, BENTON.

Massachusetts, cutting of gorges through trap ridges, EMERSON.
Holyoke trap, EMERSON.
iron mines, PUTNAM.
metamorphism of crystalline rocks, EMERSON.
Trias, DAVIS.
Upper Silurian, DALE, EMERSON.

MATTHEW (G. F.). [Sketch of geology of Frye's Island.]

New Brunswick Nat. Hist. Soc. Bull. No. 5, p. 38.

States that he had recognized the same succession of Silurian strata as is found on the Mascarene shore of Passamaquoddy Bay and that the belt of red conglomerate extending from Black's Harbor toward Eastport is Devonian.

MERRILL (F. J. H.). Geology of Long Island.

N. Y. Acad. Sci. Annals, vol. 3, pp. 341-364 and map

Describes topography and the relation and structure of the glacial and preglacial clays, sands, &c. Discusses the age and mode of deposition of the beds, condition of Long Island Sound during the glacial period, and subsidence of the coast line. The paper is accompanied by a map of the island and plate of sections.

—— [Observations on the recent formations of the Atlantic Coast of New Jersey.]

Annual Report of the State Geologist [of N. J.] for 1885, pp. 61-95.

Describes salt marshes, beaches, terraces, and alluvial deposits in general; discusses the subsidence of the coast, the formation of marshes, and change of form of the beaches due to tide and wind action.

—— On some dynamic effects of the ice sheet.

[Read to American Association, 1886.]

Brief abstract in Am. Jour. Sci. III, vol. 32, p. 324, and in Am. Ass. Adv. Sci. Proc. vol. 35, pp. 228-229.

Describes distortion of Cretaceous and Tertiary beds on Long Island, N. Y., and Southern New England. Calls attention to anticlinal deformation as the partial cause of the height of some morainal ridges and as accounting for position of certain post-Pliocene beds.

MERRILL (George P.). Notes on the composition of certain "Pliocene sandstones" from Montana and Idaho.

MERRILL (G. P.)—Continued.

Am. Jour. Sci. III, vol. 32, pp. 199-204.

Finds them to be composed in greater part of fragmental volcanic products. Describes other similar rocks from Kansas and Colorado.

MERRITT (W. H.). The Cascade anthracite coal fields of the Rocky Mountains, Canada.

Geol. Soc. Quart. Jour. vol. 42, pp. 560-564.

Describes and figures stratigraphy, structure, and relation to associated formations of Cretaceous coal beds of Bow River Valley.

Mexico, fossil man, BARCENA.
coal deposits, COPE.
mining in Oaxaca, HOOKER.

MEYER (Otto). Observations on the Tertiary and Grand Gulf [groups] of Mississippi.

Am. Jour. Sci. III, vol. 32, pp. 20-25.

Describes an unsuccessful attempt to find Grand Gulf and Tertiary beds in contact. Describes the relation of the greensands south of Enterprise and the relations near Jackson. Concludes that the Grand Gulf group is older than the marine Tertiary, was dry land when the latter was deposited, and was not a marine deposit. Calls attention to an extensive marine greensand in Eastern Mississippi at a horizon immediately below the Claiborne.

Michigan, Archean, IRVING.
iron mines, PUTNAM.

Minnesota, Archean, IRVING.
deep wells, WINCHELL.
geologic survey report, WINCHELL.
iron ore districts, WILLIS.
Lower Silurian, ULRICH.
revision of Cambrian, WINCHELL.

Mississippi, Tertiary, ALDRICH, LANGDON, HILGARD, MEYER.

Missouri, iron mines, CHAUVENET.

Mistassini expedition, LOW.

MONRO (Alex.). On the physical features and geology of Chignecto Isthmus.

New Brunswick Nat. Hist. Soc. Bulletin No. 5, pp. 20-24.

Describes some topographic feature and superficial formations; calls attention to subsidence of the land.

Montana, Cretaceous and Laramie, HAYDEN.
Pliocene sands, MERRILL, PEALE.
coals and geology, DAVIS.
coals, ELDRIDGE.
eruptive rocks, LINDGREN.

N.

Nebraska, Dakota group, HICKS.
drift, CHAMBERLIN.
Lincoln salt basin, HICKS.
Permian in, HICKS.
Quaternary volcanic sand, TODD.
well sections, HICKS.

Nevada, argentiferous lead mines, SIX.
Lake Lahontan, RUSSELL.
Washoe rocks, BECKER.

NEWBERRY (John S.). Earthquakes.

Columbia Coll. School of Mines Quarterly, vol. 8, pp. 1-19.

Incidentally discusses earthquakes and volcanoes as measures of thickness of the earth's crust.

—— North America in the ice period.

Popular Science Monthly, vol. 30, pp. 1-10 and pl.

Describes in general the glacial features of North America and discusses the iceberg theory and glacial climate.

—— Notes on the geology and botany of the country bordering on the Northern Pacific Railroad.

N. Y. Acad. Sci. Annals, vol. 3, pp. 242-270.

Besides mentioning many geologic features along the railroad, describes drift of Yellowstone Park and the Upper Missouri, the geology of the Belt Mountain district, the present and former glaciers of the Cascade Range, and the geology of the Puget Sound basin.

—— On the American Trias.

N. Y. Acad. Sci. Trans. vol. 5, pp. 18-19.

Discusses the equivalency of American and European beds. States his opinion of the probable Archean age of the crystalline rocks forming the eastern border of the Trias in New Jersey and Pennsylvania.

—— [Review of Hull on the "Geological age of the Atlantic Ocean."]

N. Y. Acad. Sci. Trans. vol. 5, pp. 78-79.

Opposes the statements in regard to the derivation of the materials of the American Paleozoic.

—— The Cretaceous flora of North America.

N. Y. Acad. Sci. Trans. vol. 5, pp. 133-137.

Gives a table showing relative positions of the plant bearing members of the Cretaceous of North America and Europe.

New Brunswick, Cambrian, BAILEY.
Chignecto Isthmus, MONRO.
Frye's Island, MATTHEW.

New Brunswick—Continued.
geologic studies, BAILEY.
geology of part of, ELLS.
surface geology, CHALMERS.

New England iron mines, PUTNAM, BENTON.
Upper Silurian, DALE.
See, also, **Massachusetts**.

New Hampshire, Upper Silurian, DALE.

New Jersey, Archean, BRITTON.
coast formations, COOK, MERRILL.
Cretaceous fauna, WHITFIELD.
Cretaceous and Tertiary, COOK, BRITTON.
fish remains, GRATACAP.
geologic report for 1885, COOK.
iron mines, PUTNAM.
Orange trap columns, IDDINGS.
Upper Silurian, DARTON.

New York, fire sand of Clinton County, BRAINERD.
fossiliferous limestone of Columbia County, BISHOP.
fossils at Canaan, DANA, DWIGHT, FORD.
geologic succession in Ontario County, CLARKE.
geologic wrinkles, GILBERT.
iron mines, PUTNAM.
Long Island, geology, MERRILL.
Lower Helderberg, Cayuga County, WILLIAMS.
Lower Helderberg, Cornwall Station, DARTON.
Niagara Falls recession, WOODWARD, GILBERT.
Niagara River, gorge and falls, HOVEY, CLAYPOLE, POHLMAN.
Onondaga salt group at Buffalo, POHLMAN.
Orange County, geology, DARTON.
peridotites near Peekskill, WILLIAMS.
place of Niagara Falls in geologic history, GILBERT.
Potsdam near Poughkeepsie, DWIGHT.
Quaternary deformation, GILBERT, MERRILL.
revision of Devonian section at Cayuga Lake, WILLIAMS.
salt mine, WRIGHT.

O.

ORTON (Edward). Address to the section of geology and geography.

Am. Ass. Adv. Sci. Proc. vol. 34, pp. 173–197.
Discusses recent progress of some branches of American geology. Reviews the literature on the formation of coal. Describes the Ohio coal field and discusses the origin of the beds of coal and associated rocks, applying the conclusions to other areas.

—— Characteristics of Ohio coals.

Tenth Census: Report on the Mining Industries of the United States, pp. 619–622.

—— Geological survey of Ohio: Preliminary report upon petroleum and inflammable gas, pp. 76, 8°, 2 maps, Columbus, 1886.

Discusses the mode of occurrence and origin of oil and gas; gives a general account of the geology of Ohio and a map; describes the oil fields and the occurrence of oil and gas in the Trenton, in the Berea grit, in the Ohio shales, and in the other formations.

—— Petroleum and natural gas in Ohio.

Science, vol. 7, pp. 560–564 and map.
Describes some geologic features of the district and the rocks passed through in drilling. The paper is accompanied by a geologic map of Ohio.

—— The recently discovered sources of natural gas and petroleum in Northwestern Ohio.

Am. Ass. Adv. Sci. Proc. vol. 34, pp. 202–204.
Describes the geology of the district and the age of the beds passed through in drilling. Calls attention to the relation of the new oil district to the Cincinnati uplift.

—— The record of the deep well of the Cleveland Rolling Mill Company, Cleveland, Ohio.

Am. Ass. Adv. Sci. Proc. vol. 34, pp. 220–222.
Gives the record of a well begun in Bedford shales and extending down into the Trenton Limestone. Discusses the identity of intermediate beds.

P.

PACKARD (A. S.). Geological extinction and some of its apparent causes.

Am. Nat. vol. 20, pp. 29-40.

PANTON (J. Hoges). Notes on the geology of some islands in Lake Winnipeg.

Hist. and Sci. Soc. of Manitoba Trans. No. 20, pp. 10.

Describes the crystalline rocks, the Silurian formations and fauna, the drift, and evidences of glaciation.

Paraguay, stones from, POHLMANN.

PEALE (A. C.). Lacustrine deposits of Montana.

Science, vol. 8, pp. 163-164.

Describes the general features of the deposits and calls attention to Merrill's discovery that they are in part composed of volcanic dust.

Pennsylvania, anthracite coal region, ASHBURNER.
- Archbald pot-holes, ASHBURNER.
- Bradford County, Chemung section, LILLEY.
- Chester and Delaware kaolin, LESLEY.
- Cornwall iron mines, LESLEY, D'INVILLIERS, WILLIS.
- gas, ASHBURNER, CARLL, CHANCE, WHITE.
- glaciation, BRANNER.
- ice of Northeastern, BRANNER.
- iron ores, PUTNAM.
- kaolin of Brandywine Summit, ASHBURNER.
- magnetites of Eastern, WILLIS.
- Montgomery County, geology, CARTER.
- oil borings, ASHBURNER.
- oil region, HOUTHUMB, CARLL.
- Oriskany in Lycoming County, WOOLMAN.
- Pittsburgh coal, LESLEY, D'INVILLIERS.
- pressure fluxion, LEWIS.
- pressure, quantity, &c. of gas, LESLEY.
- railroad cut at Gray's Ferry road, SMITH.
- report on oil, CARLL.

Pennsylvania—Continued.
- report of State geologist, 1885, LESLEY.
- Tipton Run coal, ASHBURNER.
- Washington County, mountain limestone, LINN.
- Wellersburg, fire clay, LESLEY, HARDEN.
- Wyoming Buried Valley, HILL, ASHBURNER.
- Wyoming Valley limestone, ASHBURNER.
- York County, geology, FRAZER.

Penokee-Gogebic series, VAN HISE.

Permian, in Nebraska, HICKS.

Petrography, Archean of Northwest, IRVING.
- Delaware gabbros &c., CHESTER.
- gabbros &c. near Baltimore, WILLIAMS.
- Holyoke, Mass., trap, EMERSON.
- Montana eruptives, LINDGREN.
- Penokee-Gogebic rocks, VAN HISE.
- peridotites near Peekskill, N. Y., WILLIAMS.
- rocks of Andes, KÜCH, POHLMANN.
- rhyolite, CROSS.

POHLMAN (Julius). The thickness of the Onondaga salt group at Buffalo.

Buffalo Soc. Nat. Sci. Bull. vol. 5, pp. 97-98.

Determined from a well boring 1,305 feet in depth, which passed through gypsiferous beds down to 725 feet, then through soft, red shales holding a bed of sandstone near their top.

—— The Niagara gorge.

Am. Ass. Adv. Sci. Proc. vol. 35, pp. 221-222.

Discusses details of the ancient drainage of the Niagara Falls district and the origin and work of the Niagara River.

POHLMANN (Robert). Gesteine aus Paraguay.

Neues Jahrbuch, Band I, pp. 244-248, 1886.

Describes muscovite-gneiss, biotite-gneiss, muscovite-mica-schist, quartzite, sandstone, oölite-limestones, olivine-kersantite, and nepheline-basalt.

PORTER (John B.). The iron ores and coals of Alabama, Georgia, and Tennessee.

PORTER (J. B.)—Continued.

Am. Inst. Mining Eng. Trans. p. 49 and map.

Describes occurrence of iron ores and coals and the structure and geology of the region.

POWELL (J. W.). The cause of earthquakes.

The Forum, vol. 2, pp. 370–391.

Gives instances of formation of sedimentary deposits. Explains faults and flexures. Discusses changes of shore lines, internal heat of the earth, crustal stresses, earthquakes known to have been produced by faulting, relation of volcanic activity to earthquakes, relation of geology to seismology, vertical range of earthquakes, and the condition of the interior of the earth and of its crust.

PRESTWICH (Joseph). Geology, chemical, physical, and stratigraphical. Vol. 1, Chemical and physical, 24+477 pp. 8°, Oxford, 1886.

Thinks that the Cañon of the Colorado may be due to a fissure widened by erosion. Quotes descriptions of various instances of geologic phenomena in the United States, especially in the West.

PRIME (Frederick, *jr.*). The coals of the United States.

Tenth Census: Report on the Mining Industries of the United States, pp. 605–617.

Brief general description of the location and character of the coal districts.

PUMPELLY (Raphael). Bituminous coals and lignites of the Northwest.

Tenth Census: Report on the Mining Industries of the United States, pp. 690–695 and map.

General description and notice of deposits.

—— Geographical and geological distribution of the iron ores of the United States.

Tenth Census: Report on the Mining Industries of the United States, pp. 3–36 and plates.

PUMPELLY (R.)—Continued.

General geologic description of the various ore regions and some features of their structure.

PUTNAM (Bayard T.). Notes on the samples of iron ore collected in Connecticut and Massachusetts.

Tenth Census: Report on the Mining Industries of the United States, pp. 83–87.

Describes some features of the formations in which the ore occurs.

—— Notes on the samples of iron ore collected in Michigan and Northern Wisconsin.

Tenth Census: Report on the Mining Industries of the United States, pp. 421–455.

General description of the geology of the ore districts.

—— Notes on samples of iron ore collected in New Jersey.

Tenth Census: Report on the Mining Industries of the United States, pp. 145–177.

Describes some features of the formations in which the ores occur.

—— Notes on the samples of iron ore collected in New York.

Tenth Census: Report on the Mining Industries of the United States, pp. 89–144.

Description of the geologic relations and structural features of the mines.

—— Notes on the iron ores of Pennsylvania.

Tenth Census: Report on the Mining Industries of the United States, pp. 179–221.

Occasional notice of geologic features of formations in which the ores occur.

—— Notes on the samples of iron ore collected west of the one hundredth meridian.

Tenth Census: Report on the Mining Industries of the United States, pp. 469–505.

Description of the ore beds and the associated formations in Colorado, Wyoming, Utah, California, and Oregon.

Q.

Quaternary, Alaska, ALLEN.
along Northern Pacific Railroad, NEWBERRY.
Archbald pot-holes, Pa., ASHBURNER.
British Columbia, LAMPLUGH.
Buried Valley of Newport Creek, Pa., ASHBURNER, HILL.

Quaternary—Continued.
clay structure near Newburgh, DWIGHT.
Cornwallis Island, Halifax, HONEYMAN.
drift, COOPER, SALISBURY.
drift inventory, CHAMBERLIN.

R.

RATH (G. vom). Berichte über die Umgebungen von San Francisco, Santa Cruz und Neu Almaden, Californien.

Vorträge und Mittheilungen, 1886.
Not seen.

—— Geologische Wahrnehmungen in Californien längs der Central-Pacific-Eisenbahn und in dem Goldgebiete von Dutch Flat, Placer Co.

Vorträge und Mittheilungen, 1886.
Not seen.

——Wahrnehmungen auf einer Reise durch einen Theil des südlichen Californiens sowie in den angrenzenden Gebirgen Arizonas.

Vorträge und Mittheilungen, 1886.
Not seen.

—— Wahrnehmungen in der Umgebung von Silver Cliff, Salida, Leadville und Gunnison, Colorado.

Vorträge und Mittheilungen, 1886.
Not seen.

READE (T. Mellard). The origin of mountain ranges, considered experimentally, structurally, dynamically, and in relation to geological history, pp. 359, pl. 42, 8°, London, 1886.

REYER (E.). Zwei Profile durch die Sierra Nevada.

Neues Jahrbuch, Beil.-Band IV. Heft 2, pp. 291-326 and map.

(1) Mariposa to Mono; (2) Nevada City to Reno.

Describes the geologic features along these belts and discusses the stratigraphy and structural relations and volcanism. The paper is accompanied by a geologic map of the belts and numerous illustrations of structure.

RICE (William North). On the Trap and sandstone in the gorge of the river at Tariffville, Conn.

Am. Jour. Sci. III, vol. 32, pp. 430-433.

Describes the relation of the two sheets of trap exposed in section at point.

RICHARDS (Ellen H.). First lessons in minerals, pp. 46-120, 12°, Boston, 1886. [Guides for Science Teaching.]

ROUTLEDGE (W.). The Sydney coal field, Cape Breton, N. S.

Am. Inst. Mining Eng. Trans. vol. 14, pp. 542-560.

Describes some of its geologic features.

RUSSELL (Israel C.). Existing glaciers of the United States.

Fifth Annual Report of the U. S. Geological Survey, 1883-'84, pp. 303-356, 14 pls.

Discusses the nature of a glacier and glacial action. Describes glaciers of the Sierra

RUSSELL (I. C.)—Continued.

Nevada and evidences of their former occurrence and extent. Quotes descriptions of glaciers of Northern California and the Cascade Mountains, permanent ice on mountains in the Great Basin, glaciers in the Rocky Mountains and in Alaska. The paper is illustrated with numerous cuts taken from photographs and with several maps.

—— Geological history of Lake Lahontan, a Quaternary lake of Northwestern Nevada. U. S. Geol. Surv. Monograph, No. 11, pp. 288, pls. 45, map, Washington, 1885.

After a preliminary description of the Great Basin and its exploration and a discussion of lacustral basins in general, the physiography of the Lahontan basin is described in detail, shore phenomena in general are discussed, and the shore phenomena, sediments, &c. of Lake Lahontan described. The chemistry of natural waters precedes a description of the chemic deposits of Lake Lahontan and a discussion of their formation, relations, fauna, and geologic age. In conclusion Quaternary climate is discussed and recent faults are described. The paper is illustrated by many plates from photographs and by maps and figures in the text and a folded map in a pocket.

RUTTMAN (Ferd. S.). Notes on the geology of the Tilly Foster mine.

Am. Inst. Mining Eng. Trans.

Describes and figures the ore body and fault and discusses origin of ore.

S.

SALISBURY (R. D.). Notes on the dispersion of drift copper.

Wisconsin Acad. Sci. &c. Trans. vol. 6, pp. 42–50 and pl.

Accompanied by a map showing areas in which drift copper has been found.

SELWYN (Alfred R. C.). Geological and natural history survey of Canada, annual report, n. s., vol. 1, 1885, 8°, pp. 733, and maps, Montreal, 1886.

Administrative report and papers by G. W. Dawson, McConnell, Lawson, Low, Bell, Ells, L. W. Bailey, and Chalmers, on geology; Cope, on paleontology; Coste, on mining laws; and Hoffmann, on chemic analyses.

SHALER (N. S.). Preliminary report on the geology of the Cobscook Bay district, Maine.

Am. Jour. Sci. III, vol. 32, pp. 35–60.

Describes the topography of the shore line of New England and discusses its relation to glaciation. Describes Silurian rocks with ash beds, lava flows and dikes, and the stratigraphy, structure, and paleontology of the district.

SHUMARD (Geo. G.). A partial report on the geology of Western Texas, pp. 145, 8°, Austin, 1886.

Part first: Description of the formations from the loess to the Lower Silurian between lat. 29° and 35° and long. 94° and 108°. Part second: Journal of observations between Indianola, Tex. and the valley of the Mimbres, N. Mex. Illustrated by sections. Appendix on the geology of Grayson County.

Reviewed by Hill in Am. Jour. Sci. Jan. 1886.

Sierra Nevada, post-Tertiary elevation, LE CONTE.

profiles through, REYER.

Silurian, Lower, Columbia County, N. Y., BISHOP.

fire sand, Clinton County, N. Y., BRAINERD.

fossils, Canaan, N. Y., DANA, FORD.

fossils, Orange County, N. Y., DARTON.

fossils in Potsdam, near Poughkeepsie, N. Y., DWIGHT.

fossils, Minnesota, ULRICH.

Lower Helderberg of Cayuga County, N. Y., WILLIAMS.

Lower Helderberg of Cornwall Station, N. Y., DARTON.

on border of New Jersey and New York Trias, BRITTON.

shore of Lake Champlain, WHITFIELD.

Silurian, Upper, Clinton of Ohio, FOERSTE.

Cornwall Station, N. Y., DARTON.

Lower Helderberg in New York, WILLIAMS.

of New England, DALE.

Onondaga salt group at Buffalo, POHLMAN.

SIX (A.). Les mines de plomb argentifère du district d'Eureka, États-Unis d'Amérique.

Lille, Soc. géol. du nord, annales, tome 13, pp. 14–45.

Not seen.

SMITH (Aubrey H.). The railway cutting at Gray's Ferry road.

Phil. Acad. Nat. Sci. Proc. vol. 16, pp. 253–254,

Describes exposures of clays and gravels. the former containing wood and diatoms. Gives a section in artesian well at Black's Island, Delaware River,

T.

U.

ULRICH (E. O.). Report on the Lower Silurian bryozoa, with preliminary description of some of the new species.

Geol. and Nat. Hist. Survey of Minn. 14th annual report, for 1885, pp. 55-103.

ULRICH (E. O.)—Continued.

In introductory remarks discusses equivalency of the beds just above the Saint Peter sandstone in Minnesota and southward.

Upper Silurian. See **Silurian**, Upper.

Utah, deformation of Lake Bonneville, GILBERT.

V.

VAN DIEST (P. H.). Notes on a trip to Telluride, San Miguel County, Colo.

Colorado Sci. Soc. Proc. vol. 2, pp. 28-30.

Describes geologic features of the volcanic and sedimentary rocks.

VAN HISE (C. R.). Upon the origin of the mica-schists and black mica slates of the Penokee-Gogebic iron bearing series.

Am. Jour. Sci. III, vol. 31, pp. 453-459.

Describes the stratigraphy and lithology of the rocks in question and discusses their metasomatic derivation from fragmental materials.

Vermilion Lake, iron ore districts near, WILLIS.

Vermont, geologic studies on shore of Lake Champlain, WHITFIELD.

Virginia, Rogers's Geology of, CAMPBELL.
geology of southwest part, BOYD.
iron mines, BENTON, CHAUVENET.

VOGDES (Anthony W.). Notes on the distribution of iron ores in the United States, compiled from various geological reports, pp. 24, 8°, Fortress Monroe, Va., 1886.

Occasional reference to geologic features.

W.

WALCOTT (Charles D.). Cambrian age of the roofing slates of Granville, Washington County, New York.

Am. Ass. Adv. Sci. Proc. vol. 35, pp. 220-221.

Statement of fossils found and the general stratigraphic and structural relations of the district.

—— Classification of the Cambrian system of North America.

Am. Jour. Sci. III, vol. 32, pp. 138-157.

Calls attention to the definiteness of the American Cambrian and gives a provisional key to its subdivisions. Describes the Cambrian of the Wasatch Mountains, Utah; the Eureka district, Nevada; Grand Cañon of the Colorado; Llano County, Texas; Keweenaw Point, and localities in New York, Massachusetts, and Vermont. Gives sections, discusses the fauna of the various groups and their stratigraphic positions. Discusses area of deposition of the Cambrian and gives a hypothetic map showing the supposed Keweenaw Land just before the deposition of the Upper Cambrian (Potsdam).

WALCOTT (C. D.)—Continued.

—— Second contribution to the studies on the Cambrian faunas of North America. U. S. Geol. Survey Bulletin No. 30, vol. 4, pp. 369, including 33 pls. 8°, Washington, 1886.

Discusses the terms Cambrian and Taconic and reviews previous investigations. Gives or quotes descriptions of the areas in Western Vermont; Troy, N. Y.; the St. Lawrence Valley, Newfoundland, Nevada, Utah, Texas, and elsewhere. Discusses the stratigraphic relations of the various beds and correlation of the sections. Gives table of and discusses the Cambrian faunas and their stratigraphic distribution.

WARRING (C. B.). Geologic climate in high latitudes.

Popular Science Monthly, vol. 29, pp. 352-367.

Washington, D. C., geology of, MCGEE.

Washington Territory, coals, WILLIS.

Washoe rocks, BECKER.

WENDT (Arthur F.). The pyrites deposits of the Alleghanies.

Columbia Coll. School of Mines Quarterly, vol. 7, pp. 154-188, 218-235, 301-323.

Also in Eng. and Mining Journal, vols. 41-42.

WHEELER (George M.). Report upon the third International Geographical Congress at Venice, Italy, 1881, pp. 586, 4°, Washington, 1885.

Describes geographic and geologic surveys of various countries.

WHEELER (H. A.). Temperature observations of the Lake Superior copper mines.

[Read to the St. Louis Academy of Science.] Am. Jour. Sci. III, vol. 32, p. 125.

Incidentally gives a brief description of the geology of the district.

WHITE (I. C.). The criticisms of the anticlinal theory of natural gas.

The Petroleum Age, vol. 5, No. 10, pp. 1464-1465, Nov. 1886.

In defense of the theory.

—— The geology of natural gas.

The Petroleum Age, vol. 5, No. 2, pp. 1263-1267 and map, March, 1886.

Describes anticlinal axes of Western Pennsylvania and discusses their relation to the occurrence of natural gas.

WHITFIELD (R. P.). Notice of the geological investigations along the eastern shore of Lake Champlain, conducted by H. M. Seely and Ezra Brainerd, with description of the new fossils discovered.

Am. Mus. Nat. Hist. Bulletin, vol. 1, No. 8, pp. 293-345 and pls. 24-34.

Preceded by a description of the geology of the vicinity of Fort Cassin, Vt. Describes Lower Silurian limestones and their fauna; calls attention to a fault and dike, and gives a map showing the areal geologic relations of the district.

—— The molluskan fauna of the New Jersey marls.

[Read to American Association Adv. Sci., 1886.]

Brief abstract in Am. Jour. Sci. III, vol. 32, pp. 320-321.

Discusses equivalency of the Cretaceous beds with those of the Upper Missouri section and of tne Eocene beds with those of Claiborne.

WILLIAMS (E. H. J.). A manual of lithology, 8, 135 pp. 24°, New York, 1886.

WILLIAMS (George H.). The gabbros and associated hornblende rocks occurring in the neighborhood of Baltimore, Md.

U. S. Geological Survey Bulletin No. 28, vol. 4, pp. 611-688 and 4 pl.

Describes the occurrence of the rocks and gives a map showing outcrops. Describes and figures their petrography and discusses the derivation of the gabbro-diorite from the hypersthene-gabbro.

—— The peridotites of the "Cortlandt series" on the Hudson River near Peekskill, N. Y.

Am. Jour. Sci. III, vol. 31, pp. 26-41.

Describes the petrography and distribution of the rocks of Stony and Montrose Points.

WILLIAMS (Henry S.). A revision of the Cayuga Lake [New York] section of the Devonian.

[Read to American Association, 1886.]

Brief abstract in Am. Jour. Sci. III, vol. 32, p. 321.

Discusses the fauna of the Hamilton and its relation to that of the Coralline beds, the Moscow shales, the Tully limestone, and the Genesee.

—— On the classification of the Upper Devonian.

Am. Ass. Adv. Sci. Proc. vol. 34, pp. 222-234.

Discusses the faunal relations of the beds along the lines of ten sections in Ohio, Pennsylvania, and New York, giving a table of columnar sections in illustration of his observations on the stratigraphic relations of the faunas. Calls attention to the relation of fauna to rock texture.

WILLIAMS (S. G.). Note on the Lower Helderberg rocks of Cayuga County, New York.

Am. Ass. Adv. Sci. Proc. vol. 35, pp. 214-215.

Statement in regard to fauna of strata overlying the plaster beds of Cayuga Lake.

—— The Tully limestone, its distribution, its irregularities, its character, and its life.

Abstract in Am. Ass. Adv. Sci. Proc. vol. 35, pp. 213-214, and Am. Jour. Sci. III, vol. 32, p. 320.

Also describes some structural features.

—— The westward extension of rocks of the Lower Helderberg age in New York.

Am. Jour. Sci. III, vol. 31, pp. 139-145.

Abstract in Am. Ass. Adv. Sci. Proc. vol. 34, pp. 235-236.

WILLIAMS (S. G.)—Continued.

Describes a mixed Tentaculite and Lower Pentamerus fauna in the gypsiferous limestones of Cayuga County. Gives a representation of the formation by the Tentaculite limestone at the outlet of the Skaneateles Lake, and at Oriskany Falls near Utica, by the Tentaculite overlaid by a mixed Lower Pentamerus and Delthyris shale. Calls attention to the increasing indistinctness of the divisions and the predominance of the lower portion of the formation westward. Discusses the relations of deposition to that of the Salina beds.

WILLIAMS (Samuel J.). Applied geology, pp. 386, 12°, New York, 1886.

Not seen.

WILLIS (Bailey). Notes on samples of iron ore collected in North Carolina.

Tenth Census: Report on the Mining Industries of the United States, pp. 301-329.

Description of the geologic features of some mines.

—— Notes on the samples of iron ore collected in Ohio.

Tenth Census: Report on the Mining Industries of the United States, pp. 235-243.

Description of some features of the ore bearing strata.

—— Notes on the samples of iron ore collected in East Tennessee.

Tenth Census: Report on the Mining Industries of the United States, pp. 331-350.

Notice of the geologic features at some of the mines.

—— Report of a trip on the Upper Mississippi and to Vermilion Lake, Minnesota (1880).

Tenth Census: Report on the Mining Industries of the United States, pp. 457-467.

Description of the geology of the iron bearing and associated strata and discussion of their stratigraphic and structural relations.

—— Report on certain magnetites in Eastern Pennsylvania.

Tenth Census: Report on the Mining Industries of the United States, pp. 223-234.

Describes the Cornwall, Wheatfield, Boyertown, and other mines and discusses the geologic relations of the associated formations from field studies in 1880.

—— Report on the coal fields of Washington Territory.

Tenth Census: Report on the Mining Industries of the United States, pp. 759-771.

Detailed description of the geologic and stratigraphic relations of the coal beds and as-

WILLIS (B.)—Continued.

sociated formations. The paper is illustrated by numerous colored maps and structural and columnar sections of the formations and sections and analyses of the coal beds.

WINCHELL (A.). Geologic studies or elements of geology, 26, 513 pp. 12°, Chicago, 1886.

Text book embracing many illustrations of American geologic features.

—— Sources of trend and crustal surplusage in mountain structure.

Am. Ass. Adv. Sci. Proc. vol. 34, pp. 209-212.

—— Walks and talks in the geological field, 8°, New York, 1886.

WINCHELL (N. H.). Notes on some deep wells in Minnesota.

Geol. and Nat. Hist. Survey of Minn. fourteenth annual report, for 1885, pp. 11-16 and 348-353.

Record of wells in Minneapolis, Saint Peter, Mankato, Herman, Brown Valley, Milbank, Rosenfeld Station, Sleepy Eye, Austin, Albert Lea, Morristown, Tracy, and Gibben, in Minnesota and adjacent States, and discussion of the horizon of some of the beds passed through.

—— Revision of the stratigraphy of the Cambrian in Minnesota.

Geol. and Nat. Hist. Survey of Minn. fourteenth annual report, for 1885, pp. 325-337.

Describes geologic studies in the valley of the Minnesota and discusses the position of the Saint Peter sandstone, Shakopee limestone, Saint Lawrence limestone, New Richmond beds, magnesian limestone, Jordan sandstone, and other associated beds.

—— Geological and natural history survey of Minnesota, fourteenth annual report, for 1885, pp. 353, 2 pls. 8°, Saint Paul, 1886.

Administrative report. Papers on geology, by Winchell, Ulrich, and F. L. Washburn; on paleontology, by Ulrich and Winchell; on entomology, by O. W. Oestland; on conchology, by U. S. Grant; bibliography of foraminifera, by Woodward; and on mineralogy, by Winchell.

—— The Taconic controversy in a nutshell.

Science, vol. 7, p. 34.

A plea for the retention of the term "Taconic."

Wind action, STONE.

Wisconsin, Archean, IRVING, VAN HISE.
iron mines of Northern, PUTNAM.
Penokee-Gogebic series, VAN HISE.

WOODWARD (Robert S.). On the rate of recession of Niagara Falls.

[Read to American Association, 1886.]
Brief abstracts in Am. Jour. Sci. III, vol. 32, pp. 322–323, and in Science, vol. 8, p. 205.
Comparison of results of recent and former surveys.

WOOLMAN (Lewis). Oriskany sandstone in Lycoming County, Pa.

Phila. Acad. Nat. Hist. Proc. vol. 16, pp. 297–298.
Describes occurrence of a line of outcrop not shown on geologic maps.

WORTHEN (A. H.). The Quaternary deposits of Illinois.

Am. Ass. Adv. Sci. Proc. vol. 34, pp. 214.
States contents of paper, which is to be published in vol. 13 of the Geological Survey of Illinois.

WRIGHT (G. F.). A salt mine in Western New York.

Science, vol. 8, p. 52.
Describes salt bed and strata passed through in a 1,105-foot shaft.

Wyoming, eocene deposits of, MARSH.
report on geology, AUGHEY.

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. xx, 338 pp. 35 pl. Price $1.15.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1885. 4°. xviii, 243 pp. 56 l. 56 pl. Price $2.70.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. xiv, 288 pp. 46 pl. Price $1.75.

XII. Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. 1886. 4°. xxix, 770 pp. 45 pl. and atlas of 35 sheets folio. Price $8.40.

The following is in press:

XIII. Geology of the Quicksilver Deposits of the Pacific Slope, with atlas, by George F. Becker.

The following are in preparation:

I. The Precious Metals, by Clarence King.

— Gasteropoda of the New Jersey Cretaceous and Eocene Marls, by R. P. Whitfield.

— Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague.

— Lake Bonneville, by G. K. Gilbert.

— Sauropoda, by Prof. O. C. Marsh.

— Stegosauria, by Prof. O. C. Marsh.

— Brontotheridæ, by Prof. O. C. Marsh.

— The Penokee-Gogebic Iron-Bearing Series of North Wisconsin and Michigan, by Roland D. Irving.

— Younger Mesozoic Flora of Virginia, by William M. Fontaine.

— Description of New Fossil Plants from the Dakota Group, by Leo Lesquereux.

— Report on the Denver Coal Basin, by S. F. Emmons.

— Report on Silver Cliff and Ten-Mile Mining District, Colorado, by S. F. Emmons.

— Flora of the Dakota Group, by J. S. Newberry.

— The Fossil Fishes and Fossil Plants of the Triassic Rocks of New Jersey and the Connecticut Valley, by J. S. Newberry.

BULLETINS.

Each of the Bulletins contains but one paper and is complete in itself. They are, however, numbered in a continuous series, and may be bound in volumes of convenient size. To facilitate this, each Bulletin has two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1 to 45 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining values of troy ounces of fine metal, etc., by Albert Williams, jr. 1883. 8°. 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian, along the meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A Catalogue of Geological Maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.

9. Report of work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary Studies, by Charles D. Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin, with Descriptions of New Forms, by R. Ellsworth Call. Introduced by a Sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 3 pl. Price 5 cents.

13. Boundaries of the United States and of the several States and Territories, by Henry Gannett. 1885. 8°. 135 pp. Price 10 cents.

14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.

15. On the Mesozoic and Cenozoic Paleontology of California, by Charles A. White. 1885. 8°. 33 pp. Price 5 cents.

16. On the Higher Devonian Faunas of Ontario County, New York, by John M. Clarke. 1885. 8°. 86 pp. 3 pl. Price 5 cents.

17. On the Development of Crystallization in the Igneous Rocks of Washoe, Nevada, by Arnold Hague and Joseph P. Iddings. 1885. 8°. 44 pp. Price 5 cents.

ADVERTISEMENT.

18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Charles A. White. 1885. 8°. 26 pp. 3 pl. Price 5 cents.

19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. 28 pp. Price 5 cents.

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. 114 pp. 1 pl. Price 10 cents.

21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. 16 pp. 5 pl. Price 5 cents.

22. On New Cretaceous Fossils from California, by Charles A. White. 1885. 8°. 25 pp. 5 pl. Price 5 cents.

23. Observations on the Junction between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point, Lake Superior, by R. D. Irving and T. C. Chamberlin. 1885. 8°. 124 pp. 17 pl. Price 15 cents.

24. List of Marine Mollusca, comprising the Quaternary fossils and recent forms from American Localities between Cape Hatteras and Cape Roque, including the Bermudas, by William H. Dall. 1885. 8°. 336 pp. Price 25 cents.

25. The Present Technical Condition of the Steel Industry of the United States, by Phineas Barnes. 1885. 8°. 85 pp. Price 10 cents.

26. Copper Smelting, by Henry M. Howe. 1885. 8°. 107 pp. Price 10 cents.

27. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1884–'85. 1886. 8°. 80 pp. Price 10 cents.

28. The Gabbros and Associated Hornblende Rocks occurring in the Neighborhood of Baltimore, Md., by George H. Williams. 1886. 8°. 78 pp. 4 pl. Price 10 cents.

29. On the Fresh-water Invertebrates of the North American Jurassic, by Charles A. White. 1886. 8°. 41 pp. 4 pl. Price 5 cents.

30. Second Contribution to the Studies on the Cambrian Faunas of North America, by Charles D. Walcott. 1886. 8°. 369 pp. 33 pl. Price 25 cents.

31. A Systematic Review of our Present Knowledge of Fossil Insects, including Myriapods and Arachnids, by Samuel H. Scudder. 1886. 8°. 128 pp. Price 15 cents.

32. Lists and Analyses of the Mineral Springs of the United States; a Preliminary Study, by Albert C. Peale. 1886. 8°. 235 pp. Price 20 cents.

33. Notes on the Geology of Northern California, by Joseph S. Diller. 1886. 8°. 23 pp. Price 5 cents.

34. On the relation of the Laramie Molluscan Fauna to that of the succeeding Fresh-water Eocene and other groups, by Charles A. White. 1886. 8°. 54 pp. 5 pl. Price 10 cents.

35. The Physical Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1886. 8°. 62 pp. Price 10 cents.

36. Subsidence of Fine Solid Particles in Liquids, by Carl Barus. 1887. 8°. 58 pp. Price 10 cents.

37. Types of the Laramie Flora, by Lester F. Ward. 1887. 8°. 354 pp. 57 pl. Price 25 cents.

38. Peridotite of Elliott County, Kentucky, by Joseph S. Diller. 1887. 8°. 31 pp. 1 pl. Price 5 cents.

39. The Upper Beaches and Deltas of the Glacial Lake Agassiz, by Warren Upham. 1887. 8°. 84 pp. 1 pl. Price 10 cents.

40. Changes in River Courses in Washington Territory due to Glaciation, by Bailey Willis. 1886. 8°. 10 pp. 4 pl. Price 5 cents.

41. Fossil Faunas of the Upper Devonian—the Genesee Section, New York, by Henry S. Williams. 1886. 8°. 121 pp. 4 pl. Price 15 cents.

42. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1885–'86. F. W. Clarke, chief chemist. 1887. 8°. 152 pp. 1 pl. Price 15 cents.

43. On the Tertiary and Cretaceous Strata of the Tuscaloosa, Tombigbee, and Alabama Rivers, by Eugene A. Smith and Lawrence C. Johnson. 1887. 8°. 189 pp. 21 pl. Price 15 cents.

44. Bibliography of North American Geology for 1886, by Nelson H. Darton. 1887. 8°. 35 pp. Price 5 cents.

45. Present Condition of Knowledge of the Geology of Texas, by Robert T. Hill. 1887. 8°. 94 pp. Price 10 cents.

Numbers 1 to 6 of the Bulletins form Volume I; Numbers 7 to 14, Volume II; Numbers 15 to 23, Volume III; Numbers 24 to 30, Volume IV; Numbers 31 to 36, Volume V; Numbers 37 to 41, Volume VI; Numbers 42 to 46, Volume VII.

The following are in press:

46. The Nature and Origin of Deposits of Phosphate of Lime, by R. A. F. Penrose, jr.

47. Analyses of Waters of Yellowstone National Park, by F. A. Gooch and J. E. Whitfield.

48. On the Form and Position of the Sea Level, by R. S. Woodward.

49. On the Latitude and Longitude of Points in Missouri, Kansas, and New Mexico, by R. S. Woodward.

50. Invertebrate Fossils from California, Oregon, Washington Territory, and Alaska, by C. A. White.

51. On the Subaërial Decay of Rocks and the Origin of the Red Color of Certain Formations, by Israel C. Russell.

ADVERTISEMENT.

In preparation:

— The Glacial Lake Agassiz, by Warren Upham.
— Notes on the Geology of Southwestern Kansas, by Robert Hay.
— On the Glacial Boundary, by G. F. Wright.
— Geology of the Island of Nantucket, by N. S. Shaler.
— Author Catalogue of Contributions to North American Geology, 1790-1886, by Nelson H. Darton.
— The Gabbros and Associated Rocks in Delaware, by F. D. Chester.
— Report on the Geology of Louisiana and Texas, by Lawrence C. Johnson.
— Fossil Woods and Lignites of the Potomac Formation, by F. H. Knowlton.
— Contributions to the Mineralogy of the Pacific Coast, by W. H. Melville and Waldemar Lindgren.

STATISTICAL PAPERS.

A fourth series of publications, having special reference to the mineral resources of the United States, has been undertaken.

Of that series the following have been published:

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Mineral Resources of the United States, 1885. Division of Mining Statistics and Technology. 1886. 8°. vii, 576 pp. Price 40 cents.

Mineral Resources of the United States, 1886, by David T. Day. 1887. 8°.

Correspondence relating to the publications of the Survey and all remittances (which must be by POSTAL NOTE OR MONEY ORDER, not stamps) should be addressed

TO THE DIRECTOR OF THE
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

WASHINGTON, D. C., *January* 31, 1888.

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 45

WASHINGTON
GOVERNMENT PRINTING OFFICE
1887

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

THE PRESENT CONDITION OF KNOWLEDGE OF THE GEOLOGY OF TEXAS

BY

ROBERT T. HILL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1887

CONTENTS.

PREFATORY NOTE.

Geologic investigation in Texas has been fragmentary and unsatisfactory for many reasons: hostile Indians till recently ravaged the western half of the State; the civil war suspended the work of a comprehensive geological survey inaugurated under the State legislation of 1858, and that survey resuscitated and a later organization both came to naught. The U. S. Geological Survey has extended its operations into the State too recently to increase greatly the published knowledge of the geology of Texas.

To study intelligently the geology of this State it is important that a digest of such material as has been already published should be made. The present bulletin comprises an historical statement of such scientific work as has added to available knowledge of the topography and the paleontology as well as the geology of the State, but it is not intended to include unpublished knowledge gained by my residence and study in the State, except as that knowledge modifies comments on conclusions already in print. Other publications will embody such matter in due time. The present work does not extend the record beyond January 1, 1886.

PRESENT KNOWLEDGE OF THE GEOLOGY OF TEXAS.

By Robert T. Hill.

I. HISTORICAL STATEMENT RESPECTING GEOLOGIC INVESTIGATION.

KNOWLEDGE AT THE BEGINNING OF THIS CENTURY.

Geology as a distinct science is so recent that we should not expect to find specific information upon that subject in early records; but geologic facts worthy of our attention are sometimes discernible in the descriptions of local geography and natural history given by intelligent travelers. The most complete and trustworthy compilation of the early Spanish, French, and Mexican authorities, with other historical data, is to be found in a work prepared by William Kennedy,[1] which is preferable to many later histories because of the scholarly and unprejudiced manner in which it was written.

The knowledge derived from previous authorities was embodied in the works of Baron Friedrich Heinrich Alexander von Humboldt, who visited Spanish America in the employ of Spain in the years 1799–1804, collecting all available information.

Although his studies extended into this century, his writings may justly be considered a correct statement of the geologic and geographic knowledge at the opening of the century. He first attempted to represent the principal features of the region on a map which accompanies the Voyage au régions équinoctiales du Nouveau Continent, par A. de Humboldt et A. Bonpland. His physical observations upon the mountains and plains, his numerous measurements of the region of the Upper Rio Grande, and his formulation of meteorologic laws concerning that region were all valuable, though indirect, contributions to our knowledge of Texas, which it seems he did not visit personally. A glance at his map is sufficient to show that the conception he possessed of this region, although the best of his time, was vague and indefinite. The sources and the courses of the rivers are incorrectly delineated. Streams having their sources in the eastern portion of the plains are represented as originating in lakes, an error probably arising from the fact that in the vicinity of San Antonio de Bexar, which at that time was the nucleus of Spanish settlement, the water courses arise from outbursting springs which usually expand into extensive pools of water. These phenomena

[1] Texas: The Rise, Progress, and Prospects of the Republic of Texas. By William Kennedy, esq. In two volumes. London, 1841. 8°.

are purely local, however, and the streams of Texas as a general rule are but the seaward continuation of long arroyos usually dry in the beginning of their courses.[1] The latitude and the longitude of all interior places are incorrectly given by many degrees.

The delineation of the old Spanish roads across Texas is also a feature of Baron von Humboldt's map indirectly bearing upon the geographic and geologic knowledge of the last century, for they indicate the extent of the country that came under the observation of the travelers of that time. They also indicate that the Spanish inhabitants were familiar with some of the results of one of the characteristic geologic features of Texas, for a road leads to the Paleozoic region of the San Saba, where it is certain that extensive explorations for minerals and some mining operations were conducted by them.[2]

ANGLO-AMERICAN ADVENTURERS AND COLONISTS.

The general exclusion of foreigners from the region while it was a province of the viceroyalty of New Spain, at the close of the last and in the beginning of the present century, tended to prevent exploration similar to that then going on in the United States, where the war of the Revolution had hardly closed before an epoch of scientific experiment and exploration was inaugurated. Before two decades of the present century had passed, governmental and private expeditions had explored a great portion of the territory of the United States as then defined. According to William Kennedy, who occupied a diplomatic position at a later period in Mexico,[3] "it will readily be inferred that the success of the United States in achieving their independence and the rapid growth of the federation were not regarded with indifference by the intolerant and suspicious government of Spain, whose step-dame treatment of its transatlantic dependencies supplied abundant cause of disaffection. Lest the dreaded principles of the North American Republic should contaminate the populous districts of Mexico, it became more than ever necessary to guard against the intrusion of foreigners through Texas. The feelings entertained by the Spanish authorities were manifested in a favorite saying of a captain general of the eastern internal provinces * * * that, had he the power, he would prevent the birds from flying across the boundary between Texas and the United

[1] Attention is here called to the misapplication of the old Spanish names by American travelers of this century, to be seen on comparison of any recent map with Humboldt's. It may have been the natural result of the confusing manner in which the Spaniards applied the terms "muddy" and "red" to all streams within this region that we have a great multiplication of "Red," "Colorado," "Pecos," and "Puercos" rivers throughout the Southwest.

[2] Traditions of these old Spanish mines still cause the people of Central Texas to spend much time in endeavoring to find precious minerals in the various formations of that region.

[3] Texas: The Rise, Progress, and Prospects of the Republic of Texas. By William Kennedy, esq. In two volumes. Vol. I, p. 236. London, 1841.

States. Perpetual imprisonment, at least, awaited the unlucky wanderer who was caught on the forbidden soil without the protection of a special license." It is not to be understood, however, that the Spanish government was not in its way a most liberal patron of natural science; its encouragement of Humboldt affords sufficient evidence of this. It must be remembered, however, that the time of which we write (1790–1810) was one of peculiar relations to scientific work in New Spain. Not only did the Spanish government, after its manner, encourage science, but, according to the laws of the Indies, which governed the supreme courts of Spanish America, permission to travel was procurable only upon condition that its object was research in natural history. The fact must not be forgotten, on the other hand, that the diluvian theory of that day had not yet met disastrous defeat from the stratigraphists and that the church that governed New Spain still directed and defined the scope of scientific exploration within its territory, and infidel observations were considered no more desirable by the clergy than were Anglo-American explorations by the state. These, also, were the last days of Spain's tottering rule in Mexico, and soon the revolution that ultimately freed the latter country from her power formed another serious obstacle to investigations of Spanish America by citizens of the United States.

PHILIP NOLAN.

Notwithstanding the numerous difficulties, an irrepressible spirit of adventure led many citizens of the United States into Spanish territory. To one of these we are indebted for the first Anglo-American contribution to the knowledge of the geography of Texas. Philip Nolan, a frontier trader, an Irishman by birth, in 1797 made a trading expedition into the Province of Texas from Natchez, Miss., at that time the outfitting town of the southwestern border. He was a shrewd observer and recorded his impressions of the country, which, on his return to Natchez, he published in a small work accompanied by a topographic map, his being the first description of Texas by an actual observer printed in the United States. The results were trifling, the map was incorrect and restricted, and, moreover, the book is practically out of existence. Upon returning to Texas, Nolan paid the penalty of death for his offense against Spanish jealousy, being shot while resisting capture March 21, 1801.

Others soon followed Nolan, notwithstanding the watchfulness of the Spaniards. None of these, however, except one or two military explorers, referred to hereafter, left written reports of their labors.

AMERICAN COLONIZATION PERIOD.

The Anglo-American adventurers who had so assiduously penetrated the Spanish possessions brought back to the United States many reports of the fertility of the region. The Spaniards cared little for the land

and were desirous of securing actual settlers. The combination of these two facts resulted in that unique epoch of the history of Texas now generally spoken of as the period of colonization under the empresario grants,[1] 1820–1834, during which time Anglo-American settlers gained a firm foothold in what had hitherto been the jealously guarded territory of Spain. During this period Mexico threw off the Spanish yoke, which gave increased impetus to Anglo-American settlement of Texas.

The Spanish system of empresario or contract grants of land was as follows: The authorities gave large tracts to parties or companies upon condition that they would locate upon them a certain number of colonists. The metes and bounds of these grants were not defined by actual surveys, but by certain vaguely understood natural boundaries, such as the streams and mountains. This system of land grants obviated the immediate necessity for governmental topographic surveys and permitted the location of lines to be intrusted to individuals, which much confused the topographic knowledge of the state.

Stephen F. Austin, who on the death of his father, Moses Austin, inherited the latter's concessions, also succeeded him as leader of a body of immigrants from Missouri, and conducted the first colony from the United States to Texas, at the time (1821) a portion of Mexico. He was a man of more than ordinary intelligence, and, pursuing a different course from that adopted by most of the men who accepted the empresario grants, before locating his colony he personally explored the region granted him. He made a practical contribution to the knowledge of the country by means of many articles in the newspapers of the Northern United States and he compiled a map of Texas that was far superior to any that had previously been published.

Mary Austin Holley, in 1833, wrote a small work upon Texas, which gave popular descriptions of its natural history and topography, but was not of marked value to science.

The Texan war of independence (1834–1836), the Texan Republic (1836–1845), and the war of the United States with Mexico (1846) marked years unproductive of important Anglo-American contributions to scientific knowledge of Texas, although a map was issued by Messrs. Hunt and Randall, of the Texas land office, in 1835. They also published a small guide to Texas. The Santa Fé expedition took place during this time, but its annals contain nothing of definite scientific value.[2]

EUROPEAN INVESTIGATORS.

We owe to foreign investigators the greater portion of the knowledge we now possess of the geologic features of Texas. The writings of Baron von Humboldt have already been mentioned. During the political

[1] See various histories of Texas: Thrall, Kennedy, Foote, and others.

[2] See Narrative of the Texan Santa Fé Expedition. By George Wilkins Kendall. Harper Brothers, New York, 1850.

troubles incident to the war of Texan independence and its accompanying excitement several distinguished foreigners visited the region, and to them we owe not only the first purely scientific information but also by far the most satisfactory geologic treatise yet published regarding Texas.

WILLIAM KENNEDY.

The British government in the year 1838 sent William Kennedy upon a diplomatic mission to the young Republic of Texas. This gentleman, in addition to a most liberal education, possessed very keen powers of observation, which had been greatly sharpened by years of cosmopolitan travel. While in Texas he closely studied the topography, natural history, and geology of the country, and upon his return to England he published, in 1841, the first intelligent statement of the natural and political history of Texas and the first scientific description of the country based upon personal observation.

Considering the time and the conditions under which this work was written, too much praise cannot be bestowed upon it. Its title page[1] makes no allusion to the valuable scientific matter it contains, and to this alone can I attribute the fact that the book is so little known to scientific men. Book I of Volume I, consisting of 200 octavo pages, is entirely devoted to the "Geography, natural history, and topography of Texas," and contains much of the knowledge set forth by later writers, most of whom, strange to say, have not mentioned this fountain head of their information.[2]

Although the contribution was small in volume and general in character, it justly deserves the following credit:

(1) It gives the first carefully compiled topographic map of the region. This map represents authentically the state of geographic knowledge of Texas in the year 1839 and is far superior in points of detail, accuracy, and completeness to any of the maps that had been compiled previously or that appeared at about the same period.[3]

(2) It presents the first geologic description of the country. This description, although short and untechnical, outlines much of what later workers have more carefully described and published, excepting that of a purely paleontologic nature.

(3) It has the first intelligent description of the natural history of the country.

Mr. Kennedy gives first an account of the geographic extent and boundaries of the country and its natural divisions. Stating the "remarkable contrast between the border sections and the lands of the interior," he next deals with the seacoast peculiar to this region, and

[1] Texas: The Rise, Progress, and Prospects of the Republic of Texas. By William Kennedy, esq. In two volumes. London, 1841.

[2] Dr. Roemer is a notable exception.

[3] Hunt and Randall's and Scherpf's maps appeared about the same time as this.

he notes the "alluvial accumulations and encroachments of the land on the gulf." He also gives a general hydrographic view of the State and a comparison of the rivers on the eastern side with those on the western side of the Rocky Mountains, describing many physical features that have now become the common basis of all descriptions.

He devotes an entire chapter to the peculiar climatology of Texas, a subject of great importance in the superficial geology of the State, and one the peculiarities of which Mr. Kennedy described most ably, considering the state of knowledge at the time he wrote. The zoölogic and botanic resources are given, and he was the first to describe the "cross timbers," a unique feature of the country which still remains an unsolved geologic problem.

Mr. Kennedy in describing the general features of the country notices the great extent of the Cretaceous formation in Texas and mentions for the first time in print the older Paleozoic strata. He speaks of fossils, of the various minerals, of "peculiar species of stone," &c. The appearance of asphaltum is mentioned, as well as the superabundant petrified woods of Texas. Mr. Kennedy also gives us the most complete and trustworthy enumeration of the early Spanish, French, and Mexican explorations in Texas.

G. A. SCHERPF.

An emigration movement in Germany gave an impulse at this period to another series of investigations. We probably owe the first German description of Texas to G. A. Scherpf, who in 1841 published a work[1] accompanied by two maps, one being a map of the country to the Pacific Ocean and the other a map of Texas, compiled from the material of the General Land Office of the Republic, in 1839, by Richard S. Hunt and Jesse F. Randall.

The work, as indicated by Dr. Ferd. Roemer, is valuable from the fact that it is based upon the personal observations of the author during a long residence in the country, though Dr. Roemer generally found through observations of the region here and there that Scherpf had painted his picture in too glowing colors.

PRINCE CARL SOLMS-BRAUNFELS.

In connection with the Mainz-Verein, a company organized to facilitate German emigration to Texas, much was published concerning the country. The patrons of the movement were German noblemen, who organized the union at Mayence in the spring of 1844.

In 1846 Prince Carl Solms-Braunfels, the chief promoter of the union and at that time its resident agent in Texas, published and distributed

[1] Entstehungsgeschichte und gegenwärtiger Zustand des neuen, unabhängigen, amerikanischen Staates Texas. Ein Beitrag zur Geschichte, Statistik und Geographie dieses Jahrhunderts. Im Lande selbst gesammelt von G. A. Scherpf. Augsburg, 1841. 8°, pp. vi, 154, 2 maps.

throughout Germany a handbook for emigrants to Texas, accompanied by two maps.[1]

VICTOR BRACHT.

Victor Bracht added to the German works of this period one[2] describing Texas in the year 1848. It contained a few references to the topography and the natural history of the State, but it was mainly an enthusiastic appeal for German emigration.

FERDINAND ROEMER.

In 1845 Dr. Ferdinand Roemer, the distinguished geologist and paleontologist, visited Texas to make a scientific study of its adaptation to German settlement. Dr. Roemer was in the State from December, 1845, the month of annexation, until April, 1847. His labors resulted in the most valuable contributions to the knowledge of the geology of Texas that have yet been made. These were published as follows:[3] Two preliminary papers in the American Journal of Science and Arts and two volumes in German, whose titles, given below, may be respectively translated as "Texas, with especial reference to German emigration and the physical condition of the country, based upon personal observations," Bonn, 1849, and "The Cretaceous formation of Texas and its organic remains, with a description of the Tertiary and Paleozoic strata appended," Bonn, 1852.

These works contain the first purely scientific discussions of Texas. The volume first named, as its title indicates, was chiefly written for

[1] Texas: Geschildert in Beziehung auf geographischen, socialen und übrigen Verhältnisse, mit besonderer Rücksicht auf die deutsche Colonisation. Ein Handbuch für Auswanderer nach Texas. Seinen deutschen Landsleuten gewidmet von Carl Prinzen zu Solms-Braunfels; nebst zwei Karten von Texas. Frankfurt-am-Main, 1846. 8°.

[2] Texas im Jahre 1848, nach mehrjährigen Beobachtungen dargestellt von Victor Bracht (seit 1845 Burger jenes freien Staates). Elberfel und Iserlohn, 1849, bei Bädeker. 8°.

[3] Following is a list of the writings of Dr. Ferdinand Roemer on the geology of Texas:

(1) "A Sketch of the Geology of Texas; by Dr. Ferdinand Roemer. (In a letter to the editors dated New Braunfels, German settlement on the Guadaloupe, in Western Texas, Comal County, June 12, 1846)." Am. Jour. Sci., 2d ser., Vol. II, pp. 358–365 1846.

(2) "Contributions to the Geology of Texas; by Dr. Ferdinand Roemer." Am. Jour. Sci., 2d ser., Vol. VI, pp. 21–28, 1848.

(3) Texas: Mit besonderer Rücksicht auf deutsche Auswanderung, und die physischen Verhältnisse des Landes nach eigener Beobachtung geschildert von Dr. Ferdinand Roemer. Mit einem naturwissenschaftlichen Anhange und einer topographisch-geognostischen Karte von Texas. Bonn, bei Adolph Marcus, 1849. 8°, pp. xiv, 2, 464, with map.

(4) Die Kreidebildungen von Texas und ihre organischen Einschlüsse, von Dr. Ferdinand Roemer. Mit einem die Beschreibung von Versteinerungen aus paläozoischen und tertiären Schichten enthaltenden Anhange und mit 11 von C. Hohe nach der Natur auf Stein gezeichneten Tafeln. Bonn, bei Adolph Marcus, 1852. 4°, 100 pp., with plates.

German emigrants, but its contents include much valuable scientific matter in addition to the first geologic map of Texas. This was printed in colors, indicating the superficial distribution of the formations. Although crude and imperfect, it contains all the definite information of the region then accessible and most of what has been delineated on more recent maps.

The scientific contents of this work, in addition to the above described map, are as follows:

(1) The geographic position and bounds of the State.

(2) A description of the topographic features of the country.

(3) Its general botanic and zoölogic features.

(4) Its mineral products.

(5) Bibliography of writings on Texas.

(6) Stratigraphic features of the State, including descriptions of the following formations: The diluvial and alluvial (Quaternary), the Tertiary strata, the Cretaceous strata, the older or Paleozoic strata, the Azoic[1] strata.

(7) The first contribution to the paleontology of Texas, consisting of descriptions (not figured) of the following faunas that he studied, many species of which were entirely new to science: The fossils of the Cretaceous and the fossils of the Carboniferous and Silurian strata on the San Saba River.

(8) A description by Rev. Adolph Scheele of the plants of Texas collected by Dr. Roemer.

(9) A zoölogic description of the region, giving many descriptions and localities of the radiata, articulata, mollusca, and vertebrata.

Although Mr. Kennedy had previously alluded to many of the facts here set forth, Dr. Roemer deserves the credit of developing and presenting them to the world; for, as he said at the time this publication was made, he had been unable to find a single European or American publication on the peculiar features or distribution of the geologic formations of Texas.[2] The explorations of Dr. Roemer in the western portion of the State were limited by the fact that those formations whose exploration would yield the most interesting geologic results begin where the settlements left off and where were located the hunting grounds of murderous Indian tribes.[3] So important were the geologic observations of Dr. Roemer, as announced in this volume (and a few scattering magazine articles the year before), and so minutely do they bear upon the subsequent pages of this account that it is thought desirable to give a brief résumé of the work.

(1) He outlined and discussed the age and stratigraphic conditions of the alluvial and Quaternary deposits as now generally accepted and noted the finding of fossil vertebrates[4] in many localities. He also noted the fossil exogenous woods which they contained, lamenting that their proper horizon was not known. Their occurrence with flint nodules in the detritus of the Tertiary strata he thought an indication of their Cre-

[1] Not so considered now.

[2] Texas, p. 365.

[3] Ibid., p. 366.

[4] Previously noted by Wm. M. Carpenter. See Am. Jour. Sci., 2d ser., Vol. I, p. 244.

taceous origin. He expresses the opinion that this "diluvial and alluvial" formation is composed by the sedimentation from the erosion going on in the western portion of the State.

(2) He first described the occurrence of the Eocene in Texas, at Wheelock, Caldwell County, where he found *Pleurotoma*, *Fusus*, *Turritella*, *Cerithium*, *Natica*, *Bulla*, *Dentalium*, *Cardita*, *Corbula*, *Nucula*, &c., and justly concluded that they were identical with those of the formation at Fort Claiborne, Alabama. "It is hardly to be believed," he correctly says,[1] "that this Tertiary formation is limited only to this point on the Brazos in Texas, but most probably it is part of a continuous band, as is the case in Mississippi and Alabama, extending along the foot of the Cretaceous, and only the detritus of the later alluvial formations prevents its exposure in most places."

(3) He outlined and described the Cretaceous formation of Texas.[2] "Of all the formations," said he,[3] "either eruptive or stratified, the Cretaceous formation plays by far the most important part in the geologic features of Texas."

(4) He first noted the absence of the Jurassic and the probable absence of the Triassic[4] formation from the geologic series in Texas.

(5) He first described the stratigraphic relations and the organic inclosures of the Paleozoic rocks between the Pedernales and San Saba Rivers, upon the right bank of the Colorado. This peculiar, isolated outcrop of Paleozoic strata (Potsdam of Walcott), upon the position and relations of which Mr. C. D. Walcott has lately thrown so much light, was well described by Dr. Roemer, considering the state of geologic knowledge at that time. He also noted its resemblance to a certain isolated patch of what he considered similar rocks in Missouri.

Of these rocks:

(*a*) He first recognized the Carboniferous formation, not by any lithologic peculiarity, but by its undoubted, characteristic fauna, including *Orthis umbiculatum* von Buch and *Spirifera crenistriata* Sowerby. This outcrop was the most southern exposure of the Carboniferous in Texas and Dr. Roemer was unable to explore it farther north.[5]

(*b*) He first noted the absence of the Devonian in Texas, but erroneously concluded that this formation does not extend west of the Mississippi.[6]

(*c*) He described an impure, fragmentary, semicrystalline limestone north of the Llano River, in horizontal or hardly disturbed strata, full

[1] Texas, p. 372.

[2] For details, see p. 71.

[3] Texas, p. 373.

[4] Dr. Roemer's observations did not extend westward to that portion of Texas now said by some disputants to be Jura-Trias.

[5] Innumerable allusions to "coal" are found in popular works, but most of these undoubtedly refer to the widely disseminated *true lignite* of the Cretaceous and Tertiary, which is very abundant in this portion of Texas.

[6] Texas, p. 389.

of organic remains, mostly trilobites, only one *Orthis* in addition to these having been observed.

Dr. Roemer observed the same strata some forty miles distant and described several additional organic forms, including the new species *Pterocephalia Sancti Sabæ* Roemer. This he concluded[1] was Lower Silurian. He found at another place a stratum which he also considered Lower Silurian, and which he described as consisting of a firm, white, silicious limestone containing *Euomphalus Sancti Sabæ* Roemer.

(*d*) He described the character of the older crystalline rocks that underlie the Silurian (Cambrian) strata.

Dr. Roemer's celebrated monograph (Die Kreidebildungen von Texas und ihre organischen Einschlüsse) was an elucidation of the facts he had already given in his Texas. Its chief additional points are the figures of Texas fossils and the careful, accurate descriptions of the same, as well as the more detailed account of the Texas Cretaceous. The author alluded to his descriptions in the work entitled Texas as being merely diagnoses, although they far excel in accuracy and fullness many of the descriptions since published by early American paleontologists. This work is one of the most complete and satisfactory of the early contributions to the geology of the United States, and, although printed in 1852,[2] it still remains the only monograph devoted entirely to the geology of Texas.

U. S. MILITARY RECONNAISSANCES AND EXPLORATIONS.

Principal military reconnaissances and explorations in Texas conducted by the United States Government.

	1806.	1807.	1819.	1820.	1840.	1841.	1845.	1849.	1850.	1851.	1852.	1853.	1854.	1857.	1858.
Maj. Z. M. Pike	—	—													
Freeman's exploration of Red River.		—													
Maj. S. H. Long			—	—											
Texas-Louisiana boundary					—	—									
Lieut. J. W. Abert							—								
Lieuts. Bryan, Michler, Smith, and Whiting and Capt. French								—							
Capt. R. B. Marcy								—	—	—					
Exploration of Red River (Capt. R. B. Marcy)											—				
Pacific Railroad surveys, thirty-fifth parallel (Lieutenant Whipple)												—			
Thirty-second parallel (Capt. J. Pope)													—		
United States and Mexican boundary survey (Maj. W. H. Emory)													—	—	
Artesian well experiment on Staked Plains (Capt. J. Pope)														—	—

[1] Texas, p. 388.

[2] Written in 1848–'49 on material collected from 1845 to 1847.

Our Government has always exhibited commendable enterprise in the exploration of its own territory. President Jefferson inaugurated this wise policy during his first administration by sending Lewis and Clarke upon their memorable expedition to the Northwest. Had the State of Texas shared the benefits of the first half of the century that were enjoyed by the States already in the American Union, its geologic and topographic features would now be much better understood. Notwithstanding that Texas was then part of another country, early United States explorations several times traversed its territory, as recorded in the works mentioned below.[1]

In 1806 Major Pike was ordered to ascend the Arkansas River to its source, thence to strike across the country to the head of Red River, and then descend that stream to Natchitoches. By mistake he descended the Rio Grande. He was captured by the Spanish authorities, who sent him home under escort, by way of Chihuahua, El Paso, San Antonio, and the Sabine. His work was of much geographic value concerning the Upper Arkansas region, but added little of value to scientific information concerning Texas. It failed in its original object, to discover the sources of the Red River.

The next year (1807) Lieutenant Freeman and party were sent out by President Jefferson to explore the Red River to its sources, but they were arrested near the eastern border of the present Panhandle of Texas and returned to the United States. The Spanish government, alarmed by these explorations, strengthened its fortifications on the eastern border of Texas to keep out all intruders.

The next Government expedition to penetrate Texan territory was the one conducted by Major Long, in 1819–'20. On his return from the Upper Arkansas he traveled several hundred miles down the Canadian, under the supposition that it was the Red River. A report of his journey was published.[2] This contained an interesting geographic description of the country, with some geologic facts. Although the Canadian region naturally belongs with the Indian Territory, political boundaries have included a portion of it in Texan territory, and hence to Major Long's description of it belongs the credit of being the first practical

[1] Thrall's History of Texas, p. 24.

Exploration of the Red River of Louisiana, by R. B. Marcy, &c., p. 3.

An account of expeditions to the sources of the Mississippi, and through the western parts of Louisiana, to the sources of the Arkansaw, Kans, La Platte, and Pierre Jaun Rivers; performed by order of the Government of the United States during the years 1805, 1806, and 1807. And a tour through the interior parts of New Spain, when conducted through these provinces, by order of the captain-general, in the year 1807. By Maj. Z. M. Pike. Illustrated by maps and charts. Philadelphia, 1810. 8°, pp. 7, 277; 4, 67, 55, 87, 1 portrait, 6 maps.

[2] Account of an expedition from Pittsburgh to the Rocky Mountains, performed in the years 1819 and '20, by order of the Hon. J. C. Calhoun, Secretary of War: under the command of Major Stephen H. Long. From the notes of Major Long, Mr. T. Say, and other gentlemen of the exploring party. Compiled by Edwin James, botanist and geologist for the expedition. 2 vols. Philadelphia, 1823. 8°.

contribution to geologic knowledge of Texas by the Government explorations.

Lieut. J. W. Abert, while returning from New Mexico in 1845, also descended the Canadian River through the northern portion of the Panhandle of Texas. His itinerary and the accompanying illustrations throw some light upon the physical features of the region, but convey little accurate geologic information.[1]

In 1840-'41 a joint commission, representing the United States and the Republic of Texas, ran the Louisiana-Texas boundary. The Journal of the Joint Commission affords no geologic information, although a few facts may be inferred from the meager topographic data. This exploration was exceptional in a period of reconnaissances.[2]

Government explorations were inaugurated in Texas soon after the annexation of that Republic and the subsidence of excitement incident to the war with Mexico which followed.

By the articles of annexation (1845) it was stipulated that the United States Government should protect the people of Texas from the Indians upon their western and northern borders. The settlements at that time did not extend beyond the eastern third of Northern Texas and the city of San Antonio in the south. One of the first acts of the United States Government was to establish a chain of forts from Fort Washita, Arkansas (now Indian Territory), on the Red River, to near the present site of Fort Duncan, near Eagle Pass, on the Rio Grande,[3] including Fort Worth (now the prosperous city of the same name); Fort Graham, on the Brazos, in Hill County; Fort Martin Scott, near the present town of Fredericksburg; Fort Croghan,[4] on the Colorado; and Fort Lincoln, on the Rio Seco, in the southwest corner of Medina County. This chain of fortifications became the base of a series of military explorations in Western Texas that added greatly to the fund of knowledge concerning that region.

The work accomplished was of two kinds, each of which was of some definite value to geologic knowledge. The first was work of reconnaissance for the purpose of obtaining an idea of the general topography of the country in order to facilitate military operations. The second comprised detailed surveys for purposes other than military, embracing the great surveys for the exploration of the railway routes to the Pacific, the exploration of the Red River of Louisiana, the United States and Mexican boundary survey, and an experiment in digging artesian wells on the

[1] Report of an expedition, by Lieut. J. W. Abert, on the Upper Arkansas and through the country of the Comanche Indians, in 1845. Twenty-ninth Congress, first session, Senate Document 438. Washington, 1846.

[2] Twenty-seventh Congress, second session, Senate Document 199, pp. 54-57, with maps.

[3] The northeast and southwest line of this chain of forts almost coincides with the eastern boundary of the true Texas Cretaceous area.

[4] Abandoned.

plains. All these expeditions were conducted by officers of the regular Army, frequently accompanied by scientific specialists.

The greater part of the reports of these expeditions were published, the first in 1850,[1] though some of them can only be found in manuscript in the archives of the War Department at Washington,[2] including all preceding 1849.

The character of the published reports was of every degree of value, varying in length from brief communications of only a page or two to large sets of octavo volumes replete with original matter.[3]

RECONNAISSANCES.

At the close of the Mexican war very little was known of Texas west of the line of fortifications erected in 1846–'47. Not the source of a single river heading in the great plains was definitely known and nothing whatever of the geology of that territory had been revealed.

The first military reconnaissance was that undertaken by Lieut. William F. Smith,[4] February, 1849, for the purpose of reconnoitering a wagon road from San Antonio to El Paso, a distance of 632 miles. His brief report is very general in its character, but gives many hints concerning the topographic features of the country. It contains no direct contribution to geologic knowledge.

The next expedition was conducted by Lieut. N. Michler, jr.,[5] and had for its object the reconnaissance of a military road from Corpus Christi to the military post on the Leona. His report contains numerous descriptions of the topographic features of the region traversed. Although its character is purely that of preliminary reconnaissance and its scientific allusions are vague and incidental, the report still remains one of the best descriptions of that portion of the country.

The next exploration of 1849 was that reported upon by Lieut. William H. C. Whiting.[6] The object of the undertaking can be best understood by the following extract from the original orders under which he acted:[7]

> It being very important that a military reconnaissance should be made of the western frontier of Texas, indicated by the chain of posts now established, commencing at the Rio Seco and terminating on the Red River at the mouth of the False Washita, you have been selected for that duty. You will be pleased to embrace in your report the general character of the country, the roads to be constructed between the posts, timber and stone for quarters, fuel and water, and the healthfulness of the country.

[1] Senate Ex. Doc. No. 64, Thirty-first Congress, first session, 1850. Reports of the Secretary of War. This contains reconnaissances in Texas and adjacent regions by sundry officers in 1849.

[2] For a complete map of Government explorations, see Progress Map of the United States Geographical Surveys West of the One Hundredth Meridian, 1882.

[3] Reports of the United States and Mexican Boundary Survey, 4°, 3 vols.; Pacific Railway Reports, 4°, 12 vols., &c.

[4] Senate Ex. Doc. No. 64, Thirty-first Congress, first session, 1850. Report of the Secretary of War, p. 6.

[5] Ibid., p. 7.

[6] Ibid., pp. 235–250.

[7] Ibid., p. 236.

Lieutenant Whiting's report, made in accordance with the foregoing instructions, is by far the most intelligent and comprehensive of the military reports of that year. While keeping the main object of the journey in view, he does not lose an opportunity to interpolate observations upon the geology of the region. His report, of only thirteen pages, is the best yet made of the country traversed, although its contribution to scientific knowledge is small.

A most important contribution to the topography of the region between El Paso and Fort Washita was made by Capt. Randolph B. Marcy upon his journey eastward from Santa Fé to Fort Smith. His route intercepted the headwaters of the rivers that rise along the eastern borders of the Staked Plains and was subsequently visited by the Pacific Railroad surveys. His report includes the first printed description of the region, which will be treated somewhat at length in subsequent pages.

This journey, the first of a series made by Captain Marcy in that region, furnishes the greater portion of our knowledge concerning it. The publications of his observations consist of a large map, showing the routes traversed by him during the years 1849, 1850, and 1851, and his report upon the exploration of the Red River of Louisiana, the latter belonging to the work of exploration, more fully noted hereafter.

Meanwhile Lieut. W. F. Smith, who had completed his reconnaissance of the country between San Antonio and El Paso, was detailed to explore the Sacramento Mountains west of the Pecos River. His report of the work is only two printed pages, but, comparatively, is a valuable contribution to the topography of the region, about which so little is yet known.

Lieut. Francis N. Bryan conducted another expedition in this year. His object was to survey a road from San Antonio to El Paso. His published itinerary of the forty-six days occupied in performing the journey contains much general information concerning the country traversed.

Another contribution to the geography and topography of Texas was made by Lieutenant Michler in the year 1849. He followed Captain Marcy's trail from Fort Washita to the Pecos River. Upon arriving at the Pecos he turned eastward to San Antonio. His printed report was of a general character.

Other reconnaissances were made during the succeeding years, but little has been published concerning them except what is embodied in the reports of the more detailed explorations.

EXPLORATIONS.

The work of the Government expeditions hitherto made, although often securing valuable data, was purely that of hasty military reconnaissances; but we shall see that the national authorities commenced a series of more deliberate expeditions, usually accompanied by scientific specialists, beginning with Captain Marcy's exploration of the Red River of Louisiana in the year 1852 and continuing until the completion of the United States and Mexican boundary survey in 1855, and including some minor work extending to the year 1858. Thirty-five years ago little was known of Texas west of the one hundredth meridian; even the headwaters of Red River had not been explored; to-day little is known of this region, and no map exists containing more than an approximation to its topography.

EXPLORATION OF THE RED RIVER OF LOUISIANA.

In 1852 Captain Marcy was ordered to explore Red River to its source. Upon his return he published a report[1] of the expedition, which contains the first geologic contribution of value for that part of the State. From this report is compiled the following résumé of the work accomplished by the exploration and its scientific corps:

(1) Barometric and astronomic observations were made by Lieut. George B. McClellan. Although these were oftentimes incorrect,[2] they constituted a definite contribution to the altitude of that region.

(2) A practical geologist, Dr. G. G. Shumard, accompanied the expedition and made many notes of value, communicating to the world through his own report and the reports of others upon his collections many facts concerning the local geology. His work will be further noticed in this paper.

(3) The source and the confluents of Red River were delineated upon the map.

(4) Collections of botanic and zoölogic specimens of great value were made, upon which many publications were afterwards based.

The strictly geologic work accomplished by this expedition was as follows:

(1) Dr. George G. Shumard, the accompanying geologist, gives a brief description of the country from Fort Smith, Arkansas, westward, by the way of Fort Washita (ten miles north of the present city of Denison, Tex.) and Fort Belknap, Texas, to the headwaters of Red River. His paper contains the first descriptions of the Coal Measures (Carboniferous) of the Indian Territory and Central Texas; many sections of the gypsum bearing region, commonly called the Jura-Trias or Red beds, and the best we now possess of them; descriptions of the Wichita Mountains, composed of granitic rock, which are still but little understood; and interesting data concerning the Cretaceous strata of that region.

[1] Exploration of the Red River of Louisiana, in the year 1852, by Randolph B. Marcy, captain Fifth Infantry, U. S. Army, assisted by George B. McClellan, brevet captain U. S. Engineers; with reports on the natural history of the country and numerous illustrations. Washington, 1854.

[2] Lieutenant McClellan located the one hundredth meridian nearly 70 miles east of its true position, an error which has caused considerable misunderstanding concerning the boundary of Texas.

It is to him that we owe the first presentation of these strata as they occur at Fort Washita and southward from that place in Texas.

(2) A valuable contribution to the mineralogy of the region, by Dr. Edward Hitchcock, of Amherst. His paper treats of the vast gypsum deposits and the economic and scientific value of that mineral as it occurs in Texas.

(3) Descriptions of the Carboniferous and Cretaceous fossils collected, with figures. This, the paleontologic portion of the work, was the first contribution by Dr. Benjamin F. Shumard to the geology of Texas. The figures are very poorly executed and it is doubtful whether their publication has been of value.

(4) A valuable map of the region, by Captain Marcy, accompanies the report. It contains the results of observations during many years of that officer's travels in this region.

UNITED STATES AND MEXICAN BOUNDARY SURVEY.

While Captain Marcy was exploring the northern portion of the State, another expedition was in progress upon a much larger scale along the southern boundary. This was the United States and Mexican boundary survey of 1848–1855. It is well to bear in mind the immense size of the State of Texas and to remember that Marcy's investigations were in the northwestern portion and Roemer's in the southeastern central, the United States and Mexican boundary survey being confined to the southern region.

The work of this survey in Texas commenced in the year 1853, under Major W. H. Emory, and the field work continued through the year 1854. In 1857 the report[1] of the survey was published. This is of inestimable value to science. It contains the first geologic descriptions of the great region drained by the Rio Grande. In fact, the three large quarto volumes of this report, except a few magazine articles, still form almost the sum total of the literature of that section.

The report embraces papers upon the geology of the route by Messrs. Arthur Schott, James Hall, and T. A. Conrad. Messrs. Hall and Conrad had not seen the region, but made vague and general deductions from reports and from specimens collected by members of the party. Mr. Schott's descriptions are clear and accurate so far as I have observed. Mr. Conrad's paleontologic descriptions were too often based upon material that modern paleontologists would not consider trustworthy evidence of new species. In several instances the localities he gives in the publication disagree with the ones marked by the collector, Mr. Schott, upon the specimens now in the collections of the National Museum.

[1] Report on the United States and Mexican boundary survey, made under the direction of the Secretary of the Interior, by William H. Emory, major First Cavalry and United States commissioner. Vol. I. Washington, 1857.

Dr. C. C. Parry, who wrote the paper in Major Emory's report upon the geology of the upper portion of the Rio Grande, states that the portion of the river from seventy miles below El Paso to Presidio del Norte did not come under his personal observation.[1]

These facts are given not to disparage the work, which, as already said, is by far the best contribution to the geology of the Rio Grande from El Paso to its mouth, but to show how infinitesimal is our knowledge of the region of which these small geologic reports are as yet our only authority, a section of country, following the general course of the stream, over twelve hundred miles in length.

The astronomic and topographic determinations of this survey were also very valuable and in general it is the most important and accurate addition to the cartography of Texas that has yet been made.

PACIFIC RAILROAD SURVEYS.

Another Government undertaking that followed closely upon Captain Marcy's exploration of Red River, and that was inaugurated while Major Emory's work upon the Rio Grande was still in progress, was the series of surveys across the region lying between the Mississippi River and the Pacific Ocean, commenced in the year 1853. Two of the lines crossed portions of the State of Texas.

The first of these surveys was conducted by Lieut. A. W. Whipple in 1852 and 1853 and is generally known as the thirty-fifth parallel survey.

The thirty-fifth parallel survey.—This survey traversed that extreme northwestern portion of the State locally designated as the Panhandle (all of Texas north of Red River and west of the one hundredth meridian), a region differing much in its physical aspects from the remainder of the State. The line traveled was approximately that of the Canadian River, and the results were a fair geographic section of the region and a contribution to the scientific knowledge of the Indian Territory, whereby some light was thrown upon the northern extension of the Texas formations.

Lieutenant Whipple, besides having a well equipped corps of topographic engineers, was accompanied by Mr. Jules Marcou, who as geologist took careful notes and collected many specimens. His observations were valuable, but his deductions involved American geologists of the time in a discussion that has not been settled to this day; for, while Mr. Marcou was said to be wrong in certain of his conclusions concerning the so-called Jurassic age of what is now generally accepted Cretaceous, he still possessed the advantage over his antagonists of being the only one who had visited the field. It is often a question in my mind whether Mr. Marcou's terms Jurassic and Neocomian, which he applied to the Cretaceous of Western Texas, are not much nearer the truth than those of the writers who make that portion of the Texas

[1] Report on the United States and Mexican Boundary Survey, Vol. I, Part II, p. 49.

Cretaceous the equivalent of the upper members of the European series. He was one of the first practical geologists to visit this northwestern section of Texas. His observations were limited to that small portion of the State traversed by the Canadian River, but they constitute the chief data concerning the region to which they pertain. It is much to be regretted that their usefulness was impaired by the misunderstanding that ensued between him and the Secretary of War. Before Mr. Marcou could write a final and complete report his notes were peremptorily demanded as he was departing for Europe, and later they were intrusted to Mr. W. P. Blake to write out. He published Mr. Marcou's field notes in full, although he failed in that interpretation which could have been made only by Mr. Marcou, and gave the world an opportunity to make its own deductions.

The results[1] of the thirty-fifth parallel survey, although presenting many imperfections and marred by this unfortunate occurrence, were upon the whole a great addition to our knowledge of the Indian Territory and Northwest Texas regions.

The thirty-second parallel survey.—Another survey across the State of Texas for the purpose of finding a suitable railway route to the Pacific was that conducted by Capt. John Pope along the thirty-second parallel in 1853. Practically the route was the same as the one traveled by Captain Marcy upon his return from New Mexico, in 1848, a description of which has already been given (p. 24). The work of this exploring expedition, so far as it pertained to Texas, commenced at El Paso, in the western portion of the State, and progressed eastward. It approximately followed the thirty-second parallel to near the mouth of Delaware Creek, and thence passed slightly north of eastward to Preston, on Red River, a few miles northwest of the site of the city of Denison. It crossed, en route, the Paleozoic strata of the trans-Pecos region, the Jura-Trias or gypsum bearing series, the typical Texas Cretaceous, the Central Texas Coal Measures, the two belts of the cross timbers, and the Cretaceous to the east of the central Carboniferous exposures. The astronomic, topographic, and barometric measurements were important, but the geologic results were impaired by the fact that no trained geologist accompanied the expedition. The notes of the officers and the specimens gathered under Mr. Marcou's direction, however, were turned over to him by Captain Pope, and he wrote a brief general preliminary report upon them.[2]

[1] Reports of explorations and surveys to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean, made under the direction of the Secretary of War in 1853–'54,–'55, according to the acts of Congress of March 3, 1853, May 31, 1854, and August 5, 1854. Volume III. Washington, 1856.

[2] Report of Secretary of War. House Document 129, Vol. 4, Chap. XIII, pp. 125–128. Geological notes of a survey of the country comprised between Preston, Red River, and El Paso, Rio Grande del Norte, in Report of Exploration of a Route for the Pacific Railroad near the Thirty-second Parallel of Latitude, from the Red River to the Rio Grande. By Bvt. Capt. John Pope, Corps of Topographical Engineers, 1855.

The notes and specimens of this expedition were taken from Mr. Marcou, together with those of the thirty-fifth parallel survey, and hence he was debarred from the privilege of writing the final report for the large quarto volumes that subsequently appeared.[1] These contained a written report by Mr. W. P. Blake, which gave little additional knowledge.

ARTESIAN WELL EXPERIMENT.

The last exploration in Texas conducted by military officers under specific Government appropriations was that for the purpose of boring artesian wells upon the plains, conducted by Capt. John Pope, in 1857 and 1858.[2] This experiment yielded important geologic information, for accompanying the expedition as geologist was Dr. George G. Shumard, who collected much material and wrote an article on the local geology,[3] adding much to our knowledge of the trans-Pecos region, showing the existence of the Carboniferous, the Cretaceous, and the gypsum bearing Mesozoics in that part of the State.

During this expedition Dr. G. G. Shumard collected the material that formed the ground work of Dr. B. F. Shumard's article upon "New fossils from the Permian strata of New Mexico and Texas." This paper first announced the existence of Permian strata in Texas.[4]

This work practically ended United States explorations in Texas for the time. The State then exhibited a keen desire to explore its own geologic resources. In a few years the civil war drew the energies of our military forces to a more serious field and the posts along the Texas frontier were evacuated, and until the inauguration of work by the United States Geological Survey in the State no further contributions were made by United States explorers.

GEOLOGIC SURVEYS CONDUCTED BY THE STATE.

For the information contained in the following pages I am indebted to various persons. Much of it has been compiled from the official reports

[1] Reports of explorations and surveys to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean. Made under the direction of the Secretary of War, in 1853–'54, according to acts of Congress of March 3, 1853, May 31, 1854, and August 5, 1854. Vol. II. Washington, 1855.

[2] Artesian well experiment. Reports of Capt. John Pope, Top. Eng., to Capt. A. A. Humphreys, Top. Eng., in charge of office of Exploration and Survey, War Department. To be found in Senate Ex. Doc., Thirty-fifth Congress, second session, 1858–'59, Vol. 2 (which is Report of the Secretary of War, J. B. Floyd, first part), pp. 582, 590-608.

[3] Trans. Acad. Sci. St. Louis, Vol. I.

[4] Still little understood, but now considered either Permian or uppermost Carboniferous, being the latest of the latter age.

of the several State geologists. A greater portion, however, has been kindly furnished by those familiar with the facts presented.[1]

The burning of the archives by the capitol fire in 1881 has deprived me of what under ordinary circumstances would be the most useful source of information.

To some it is a matter of surprise that the State of Texas has not made a thorough geologic survey of its territory, especially since the State has always been comparatively free from financial embarrassment and owns the public lands within its borders, the value of which could not but have been enhanced by a scientific knowledge of their characteristics. A thorough study of the political history of the State will show, however, that a combination of untoward circumstances has invariably thwarted the effect of enactments looking toward such a survey.

Up to the time when the Anglo-American population extricated Texas from the Spanish-Mexican régime (1835) it had been under the non-progressive rule of the Middle Ages. The other States of the Union had previously attained a permanent form of government, allowing the public mind to follow intellectual and scientific pursuits with the greatest impetus during the first third of the nineteenth century. Amidst the throes of political organization scientific interests always flag. Time is required for the establishment of a stable government. While undergoing its political evolution, Texas had two wars with Mexico and a continual fight with hostile savages. Twenty years from the date of its separation from Mexican domination seems but a short period for the establishment of a geologic survey.

But a still greater obstacle to an early thorough survey of its domains was the fact that the population, even until the last decade, was confined to the eastern third of the State, and that until a dozen years ago the hostility of the Indians made observation in the vast unsettled region exceedingly dangerous. In 1849 Dr. Roemer said that Texas became interesting geologically at the points where civilization left off and where exploration was almost impossible. His remarks would have been equally applicable thirty years later.

Notwithstanding these obstacles, the State of Texas did establish by legislative enactment and appropriation what was intended to be a thorough topographic and geologic survey of its domains. This honorable design was defeated by the civil war and the petty jealousies of the scientific men to whom the State had intrusted the labor. The State made two earnest endeavors to secure a geologic survey of its domain and that such a survey has not been made is not due to its indifference.

Before describing these surveys and their results, it will be well to mention briefly the Texas land office, an institution whose functions have a distant connection with scientific results.

[1] I am especially indebted to Prof. G. C. Broadhead, of Pleasant Hill, Mo.; Mr. Friench Simpson, of Columbus, Tex.; Hon. A. D. Norton, of Dallas, Tex.; Mr. C. K. Lee, of Colorado, Tex.; Hon. J. G. Tracey, of Houston, Tex., and Mr. N. A. Taylor, of Abilene, Tex.

THE TEXAS LAND OFFICE.

The Republic of Texas, having in its possession a large unsettled domain, found it necessary, as one of the first acts of its existence, to establish some method of administering the duties incident to the survey and the disposition of the land. By act of December 22, 1836, a land office was opened at the capital in February, 1838, under the control of a salaried commissioner.

The functions of this office were to preserve a record of surveys, to issue warrants for land, and to prevent error or fraud in their location. The Republic of Texas followed the Spanish method of granting lands,[1] by which the State incurred no expense of survey in their location. Instead of making topographic surveys of the public lands and dividing them according to the township system of the United States land surveys, the State issued scrip for a designated number of acres to be located upon any portion of the territory found vacant. The person locating the land employed a surveyor (oftentimes of inadequate skill), who ran the lines of the location and sent in field notes of his survey to Austin. By this method the State obtained very unsatisfactory information of these surveys. By the township system, on the other hand, at least a correct map of the main topographic features would have been secured. The land office of the State published several maps of Texas, but they were chargeable with incorrectness. Dr. B. F. Shumard said: "The maps in the land office at Austin are more or less imperfect and the surveys in some instances exceedingly erroneous;"[2] yet these maps were the only contributions of the State land office to a scientific knowledge of Texas. Their value is of a doubtful if not of a negative character. The commissioners have made regular reports to each legislative body. A few of these have been printed, but they contain nothing of scientific value. The whole series of reports can be found only in the land office at Austin.

FIRST GEOLOGICAL SURVEY (SHUMARD).

By act of the 10th of February, 1858, the legislature of the State of Texas authorized a geological and agricultural survey of the State. It was made the duty of the State geologist to make as speedily as possible "a thorough and complete geological survey of the State, so as to determine accurately the quality and characteristics of the soil and its adaptation to agricultural purposes; the species of produce to which the soil in different sections is adapted; its mineral resources, their location and the best means for their development; its water powers, their location and capacities; and generally everything relating to the geological and agricultural character of the State."[3]

---

[1] See p. 12.

[2] First Report of Progress of the Geological and Agricultural Survey of Texas, by B. F. Shumard, State Geologist, pp. 8, 9.

[3] Ibid., p. 5.

To fill the office of State geologist, which was created by the same act, Governor H. R. Runnels, on the 28th day of August, 1858, appointed Dr. Benjamin F. Shumard.[1] This gentleman's life of scientific training and his experience in geologic surveys gave him every qualification for the position.[2]

Organization and equipment.—His first act[3] was to select from the works of the best instrument makers a set of chemical and physical apparatus for the equipment of analytical laboratories at Austin and of meteorologic stations at one or two other points. Since the climatologic and meteorologic conditions existing in the State of Texas are important factors in the geologic effects, the wisdom of Dr. Shumard's endeavors to study these phenomena will be apparent.

He organized his staff of assistants as follows: Assistant geologist, Dr. George G. Shumard; chemist and assistant geologist, Prof. W. P. Riddell; topographer, Mr. A. R. Roessler; meteorologists, Prof. Caleb G. Forshey, at Rutersville, and Swante Palm, esq., at Austin.

The qualifications of all these gentlemen were considered the best for their day and time. Dr. George G. Shumard possessed the largest store of scientific information, especially concerning the western portion of the State, having accompanied Captains Marcy and Pope as a geologist in their numerous explorations.

Professor Riddell, besides being an able chemist, was especially well informed respecting the structure of the settled portion of the country.

Mr. Roessler, although a young man, possessed a good scientific education, was a hard worker, and to him is due much of the accurate topographic knowledge of the State we possess at the present day.

The meteorologic stations were established in accordance with the plan adopted by the Smithsonian Institution.

Field labors.—The geologic corps proper was divided into field parties, and in January, 1859, these entered upon their duties. The first of them, under Dr. George G. Shumard, constructed an accurate section of the country between Austin and the Red River in Grayson County. Dr. Shumard also made "thorough and final surveys" of the counties of Grayson, Fannin, and Cass, and partial surveys of Bowie, Red River, and Lamar Counties. In addition to this work, he made a

[1] There is a tradition, with some ground for belief, that Governor Runnels intended to appoint Dr. G. G. Shumard to the office of State geologist, but, by a clerical error, the name of his brother, Dr. B. F. Shumard, was inserted in the original commission. This being before the days of rapid communication it was impossible to remedy the error, and Dr. G. G. Shumard gracefully accepted the position of assistant State geologist.

[2] For a sketch of Dr. Shumard's qualifications, see Texas Almanac for 1859.

[3] The following account of the operations of the survey is principally based upon the First Report of Progress of the Geological and Agricultural Survey of Texas, by B. F. Shumard, Austin, 1859,

careful exploration of Red River from Cooke County to the Louisiana boundary.[1]

Professor Riddell made final surveys of the counties of Caldwell and Guadalupe, south of Austin, the State capital, and of McLennan and Coryell, near the geographic center of the State; also of the greater part of Bosque County.

Dr. Benjamin F. Shumard, the head of the survey, made detailed surveys of Burnet and Rush and partial surveys of Travis, Bastrop, Washington, Fayette, and Young Counties. He also made a series of reconnaissances. Dr. Shumard in his report[2] said:

It will be seen that besides a general survey extending over a large portion of the eastern and middle portions of the State, we have made minute and final surveys of eleven counties. Two are nearly finished and a number partially surveyed.

Methods of survey.—From the report cited we extract the following:

In making these preliminary surveys careful sections of the strata have been made at all points of outcrop within reasonable distances of the route traveled, and the thickness, stratigraphical order, dip, and mineral and fossil characters of the various beds have been determined with as much precision as possible. * * * In some counties sections of the strata have been measured at more than one hundred and fifty localities. * * * We made frequent barometrical observations to ascertain the elevation of the country above tide-water, and much attention has been directed to obtaining a correct knowledge of the topographical features.

We have also determined, with as much accuracy as possible, the amount and quality of timber in each county, proportion of timber and prairie, elevation of hills, depth and width of valleys, and the amount of available water power furnished by the streams.

A large share of attention has also been devoted to the agricultural capabilities of these counties. The different varieties of soils and subsoils have been carefully examined, numerous specimens have been collected for future study and analysis, and we have spared no pains to ascertain the most advantageous methods of cultivating and improving them.

Particular search has been made for minerals of economical importance, and all mines, whether of prospective or known value, have been examined with special care and the probable amount, richness, and quality of the ores determined. Samples of ores and their accompanying minerals, coals, limestones, marbles, clays, mineral waters, &c., have been collected, and are now deposited in the laboratory at Austin, for chemical analysis and final preservation in the State cabinet.[3]

---

[1] Since this work was prepared for the press the notes of Dr. G. G. Shumard have been collected and published by the State of Texas in a volume entitled "A Partial Report of the Geology of Western Texas, consisting of a General Geological Report and a Journal of Geological Observations along the Routes traveled by the Expedition between Indianola, Tex., and the Valley of the Mimbres, New Mexico, during the years 1855 and 1856; with an Appendix giving a detailed Report of the Geology of Grayson County. By Prof. George G. Shumard, assistant State geologist of Texas. Austin, State Printing Office, 1886." 8°, pp. vii, 145, with illustrations.

[2] First Report of Progress of the Geological and Agricultural Survey of Texas, by B. F. Shumard, State geologist, p. 8.

[3] Ibid., p. 8.

Of the fossils, Dr. Shumard remarked that the collection was "especially large and valuable, and, it is believed, when carefully studied will throw considerable light on some disputed points of the geology of the West and Southwest."

Maps.—On the subject of maps Dr. Shumard said:

Our county maps will embrace the areas occupied by the different geological formations, localities of workable mines, ore deposits, coals, lignites, marble and stone quarries, medicinal and other springs, furnaces, towns, post offices, churches, saw and grist mills, and boundaries of timber and prairie. This portion of our labor has often been attended with considerable difficulty, arising from the fact that the maps in the land office at Austin are more or less imperfect and the surveys in some instances exceedingly erroneous. It has been sometimes almost impossible to locate our observations with that degree of minuteness and precision which was thought desirable, but we have spared no exertions to remedy defects, supply omissions, and to make our maps as complete as possible in their geographical as well as in their geological details.

Such is a brief account of the first year's operation of the geological and agricultural survey of Texas, as stated by its director in his first annual report of progress. It is obvious that Dr. Shumard had accomplished much during this brief time and that the plans of organization and operation were such as to result in the accomplishment of one of the most valuable State surveys, could they have been carried out.

Operations of 1860.—After a brief winter's work in quarters at Austin, the Survey resumed the field in 1860. The records of the year's work are meager, for a series of misfortunes occurred by which the results of the survey, excepting a few fragments to be hereafter noted, were lost to science, and a blow was inflicted upon State encouragement of scientific investigations from which the State has not yet recovered.

The personnel of the scientific corps remained unchanged, except that at the beginning of the year Dr. Shumard employed as a collector of plants a young man, S. B. Buckley, who became a prominent figure in the subsequent history of the surveys.

From Mr. Buckley we have the only published account of the survey's operations during the year,[1] of which he speaks as follows:

In January, 1860, I was also employed as an assistant by Dr. Shumard, I having charge of the botanical department, also making geological observations.

In May, 1860, Drs. Shumard, Riddell, and myself went, via San Antonio, to Corpus Christi, returning by the way of Goliad and Lockhart to Austin. About the 1st of June we started for the survey of Navarro County, which was finished about the 1st of July; then we removed, spending the month of July in the survey of Washington County. The month of August was employed in the examination of Bastrop County. Thence returning to Austin, we went into San Saba, remaining there until November.

Dr. George G. Shumard spent the summer in Northern Texas, in Grayson, Lamar, Fannin, and other counties on the Red River. He returned to Austin in September.

During the summer Dr. B. F. Shumard had been a large portion of the time at Austin, leaving Dr. Riddell and myself in the field. At Austin he was closely watched by Governor Houston, who, being convinced that Dr. Shumard was not a suitable person for a State geologist, removed him about the 1st of November, 1860.

[1] First Annual Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, A. M., Ph. D., State geologist, Houston, 1874, p. 8.

On the same page from which the above is quoted and on the following one Dr. Buckley shows very plainly the spirit in which he served his chief. He says:

Returning in January, we found Dr. Shumard still at Austin, occupying his former room at the geological department. Dr. Moore thought it rather strange that Shumard had not vacated the office. In excuse, Dr. Shumard assured Dr. Moore that he would do nothing which would injure the interests of Dr. Moore, and that he only wished to arrange his business and start for the North. Thus assured, we started for Llano County, but on our route Dr. Moore, thinking that all might not go right at Austin, where the [secession] convention of 1861 was then in session, requested me to return and arrange specimens, and watch Dr. Shumard, with whom I was then on friendly terms. Soon after my arrival at Austin a friend informed me that Dr. Shumard was busily engaged in persuading the members of the convention to displace Dr. Moore and reinstate him in office again, and that, too, with every prospect of success. To thwart this, I drew up some charges against Dr. Shumard and placed them in the hands of Governor Houston, who showed them to some of the leading members of the convention, and nothing further was done in favor of Dr. Shumard, who soon after left for St. Louis, vowing vengeance, saying that he would break down my scientific reputation.

Mr. Roessler says:

Aside, however, from Mr. Buckley's own acknowledgment of his motive in drawing up these charges, he shows his maliciousness and willful intention, if possible, to suppress the truth by neglecting to state that when these charges were presented the legislature of Texas, in its session of 1860–'61, appointed a committee for their investigation, of which Mr. Waelder was chairman. He also neglects to state that Dr. Shumard courted an investigation and voluntarily and promptly appeared before the committee appointed, and that the utter falseness of the charges was proved by such well known gentlemen as Professor Forshey, Senator Russell, and Colonel Timmons.[1]

A State election had occurred in the fall of 1859, and after much bitterness on both sides Governor Runnells, the democratic incumbent and the patron of the survey, was succeeded by Gen. Sam. Houston, independent, who, under the influence of political and personal effort brought to bear for that end, removed Dr. Shumard, after an administration of twenty-six months.[2] Dr. Shumard left the State at the outbreak of the war, during which most of his notes, collections, and maps were lost or destroyed, and made his home at St. Louis, where he died in 1869,[3] having had no opportunity to publish an official report, but having contributed to our knowledge of the geology of Texas by his fragmentary pub-

[1] Reply to the charges made by S. B. Buckley, State geologist of Texas, in his official report of 1874, against Dr. B. F. Shumard and A. R. Roessler, p. 7.

[2] Dr. Shumard was reinstated by the legislature, in April, 1861, to prepare his final report, which was never published.

[3] For the biographical data concerning Dr. Shumard in this paper we are indebted to the sketch in the Am. Jour. Sci., 2d ser., Vol. XLVIII, pp. 294–296; to A. R. Roessler's reply to S. B. Buckley; and to Prof. G. C. Broadhead and others.

Dr. B. F. Shumard was born at Lancaster, Pa., November 24, 1820. His father afterwards removed to Cincinnati, and while he was living there Dr. Shumard graduated at Oxford, Ohio; returning to Philadelphia, he went through one course in the medical college of that city. His father then removed to Louisville, Ky., where young Shumard completed his medical studies, in 1846. He then practiced medicine in one of the interior towns of Kentucky. Here he developed his taste for paleontologic investigation, and after a few months' country practice he removed to Louisville. In this lications, of which we shall speak more definitely hereafter. The survey as carried on under his immediate successors may, for convenience, still be called the Shumard survey, as it was an attempt to continue his work rather than to inaugurate any new system of work or of organization.

Immediately upon the removal of Dr. Shumard, November, 1860, the governor appointed Dr. Francis M. Moore State geologist. He was an honorable and cultured gentleman, of much executive ability. For many years he had been the editor of The Houston Daily Telegram, then the leading newspaper of the State. It was owing to his public spirited and intelligent advocacy of its necessity that the survey was originally established.

According to Dr. Buckley[1] he himself was appointed first assistant State geologist; Dr. Riddell, who had been assistant State geologist and chemist, was retained as chemist; and Mr. Roessler was

city he became associated in scientific and professional pursuits with Dr. L. P. Yandell, and together they devoted much of their leisure to the study of geology and paleontology. Several valuable paleontologie contributions were published under their joint authorship. Dr. Shumard was an earnest and careful collector, and his cabinet at Louisville was visited by many distinguished foreigners.

Dr. Shumard's geologic talent was not long in receiving recognition. He was appointed by Dr. David Dale Owen as assistant geologist in the geological survey of Iowa, Wisconsin, and Minnesota, which was inaugurated in 1846 by authority of Congress.

Dr. Shumard was busily engaged in the field during 1848 and 1849 as the head of one of the divisions of the survey. Many of the most valuable reports upon the geology and paleontology of this survey, from his pen, "remain monuments to the industry, acquirements, and ability of their author."

Besides his share in the publication of these reports, Dr. Shumard, about the same time, published a valuable monograph, entitled Contributions to the Geology of Kentucky. In the work of the Iowa, Wisconsin, and Minnesota survey he was associated with many men who have since become eminent in the annals of North American geology, including F. B. Meek, Dr. J. Evans, Prof. A. Litton, and others.

In 1853 Dr. Shumard removed to St. Louis and was appointed assistant geologist and paleontologist of the Missouri geological survey under Professor Swallow. He labored here until the summer of 1858, when he was appointed State geologist of Texas. He arrived at Austin on October 30 of the same year and initiated the work of a survey upon a broad and comprehensive plan.

At the beginning of the war the doctor returned to St. Louis. He was obliged to leave a large part of his collections and library at Austin through the war. He again took up the practice of medicine, which he continued to the year of his death.

He had been in a declining state of health for about a year, having suffered from hemorrhage of the lungs, when his death occurred, April 14, 1869.

In St. Louis Dr. Shumard had the intellectual and social companionship of that small coterie of western scientists who made that place a scientific center for many years.

As a paleontologist he held a high rank. He was president and one of the organizers of the Academy of Science of St. Louis and a member of many other similar societies at home and abroad.

He was a man of science in the highest sense of the word and devoted himself entirely to its pursuits; in the prosecution of it he contributed more, perhaps, than any other man to the revelation of the immense resources of the Mississippi Valley.

[1] First Annual Report of the Geological and Agricultural Survey of Texas, p. 8.

retained as draftsman. In December, 1860, Drs. Moore and Buckley[1] made a short reconnaissance through the southern counties of the State, and in March they made a tour through Western Texas, during which trip the survey was suspended. The resolution suspending the survey is as follows:

Be it resolved: (1) That the geological survey be suspended, with the exception of the State geologist and chemist, who shall continue in the survey only so long as it may be necessary to make out the report hereinafter provided for.

(2) That B. F. Shumard, the State geologist, be requested to make a report of his survey so far as the survey has been completed, and for that purpose shall have control over the cabinet and rooms and his notes and the services of the chemist, and he shall receive a like salary heretofore paid the State geologist until the work be completed: *Provided,* Said report shall be made by the 1st of July next; which compensation shall be paid out of the appropriations heretofore made for the support of the geological bureau.

(3) That Dr. Francis Moore, present State geologist, be requested to make out a report of the work executed up to the present time.

Approved, April 8, 1861.

What was done towards complying with this act cannot be ascertained. It is certain that no reports were published and apparently the agitation of the civil war prevented further work. The act seems to imply an official justification of Dr. Shumard, which is not mentioned in any of Dr. Buckley's sketches of the history of the surveys.

The civil war had now broken out and Dr. Moore left for the North in July, 1861, and in 1864 died in Northern Michigan, while in the employ of a mining company.

During the war the State capitol was occupied by troops and the laboratories and the museum of the survey were converted into a manufactory of percussion caps. The magnificent specimens were taken away as curiosities or wantonly destroyed and many of the precious notes and maps were scattered to the winds.

At the opening of the war Dr. Buckley also left the South, taking with him, as has been charged by Mr. Roessler,[2] the notes of the survey. At the close of the conflict he returned to Austin, assumed charge of the collections and effects of the survey, and secured the passage of a joint resolution repealing the act of April 8, 1861, by which the survey had been suspended. He was appointed by Governor Throckmorton, in November, 1866, to take charge of the survey, notwithstanding the protests of Dr. B. F. Shumard,[3] Mr. Roessler, and others, previously of

[1] First Annual Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, p. 8.

[2] Reply to the charges made by S. B. Buckley, State geologist of Texas, in his official report of 1874, against B. F. Shumard and A. R. Roessler, p. 10.

[3] In a letter to Swante Palm, esq., under date of August 11, 1866, Dr. Shumard thus characterizes Mr. Buckley's standing in his service: "In the same article he claims that he was connected with me in the geological survey. Now, he came to me ragged and penniless, and I employed him to collect plants at one dollar per day, giving him precisely the same wages I was giving my teamsters and cooks. All the geology he knows I taught him, and that was precious little."

the survey. The unfinished report of Dr. Shumard, which the legislature in 1861 had given to Dr. Moore to complete, now fell to his charge so far as materials remained. Dr. Buckley put forth in 1866 a work entitled A Preliminary Report of the Geological and Agricultural Survey of Texas. In a prefatory note he speaks of the book as the report of work done under the supervision of Dr. Moore, adding that his connection with the survey had been longer than Dr. Moore's and that all the knowledge obtained by service under Dr. Shumard which promises to have any public value is embodied in its pages. The book contains 92 octavo pages, including title and index, and a large proportion of these pages is occupied with general statements as to agricultural operations and the whole is of little scientific value. In the words of Mr. A. R. Roessler:[1]

> It does not contain the analysis of either soils or minerals or the delineation of a single fossil, geological section, or anything else in that direction. In fact there is nothing new in it, the whole report being a poor rehash of articles published in the Texas Almanac and other periodicals.

In 1867 the political winds blew out the administration that upheld Dr. Buckley before he printed any further report. Under military rule and changes that ensued was swept away the last remnant of the original geological survey of Texas as inaugurated by Dr. Shumard nine years before, except a few disordered specimens, which were completely destroyed by the capitol fire in 1881.

Official results.—The destruction of records by the capitol fire leaves no opportunity to gather official information as to what was accomplished by the survey, but from unofficial sources I have endeavored to make up as accurate and complete a statement as possible.

There were two direct publications of the survey. The first was the First Report of Progress of the Geological and Agricultural Survey of Texas, by B. F. Shumard, State geologist. It was a pamphlet of 17 pages, of which 1,700 copies were printed for distribution. It may be found in the libraries of the National Museum and the U. S. Geological Survey at Washington. The second official publication was A Preliminary Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, 1866, already described.

Indirect results.—Although the State published so little concerning the geological investigations of the Shumard survey, the scientific men who were attached to it made known useful data concerning the geology, topography, and paleontology of the State. Dr. Shumard described many new species and contributed much to the stratigraphic knowledge of the State. His publications, based upon material gathered and observations made while connected with the State survey, are as follows:

[1] Reply to the charges made by S. B. Buckley, p. 11.

"Observations upon the Cretaceous strata of Texas," Acad. Sci. Saint Louis, Vol. I, pp. 582–590, 1860.

"Descriptions of new Cretaceous fossils from Texas," Trans. Acad. Sci. Saint Louis, Vol. I, pp. 590–610, with figures, 1860, published by Dr. C. A. White in his Contributions to Paleontology, No. 1, Eleventh Annual Rep. U. S. Geological (Hayden) Survey.

"Descriptions of five new species of Gasteropoda from the Coal Measures, and a Brachiopod from the Potsdam Sandstone of Texas," Trans. Acad. Sci. Saint Louis, Vol. I, pp. 624–627, 1851.

"State House artesian well at Austin," Texas Almanac, pp. 161, 162, 1860; gives valuable geological section.

"Geological survey of Texas," Texas Almanac, pp. 199, 200, 1860, Galveston, 1859.

"The Primordial zone of Texas, with descriptions of new fossils," Am. Jour. Sci., 2d ser., Vol. XXXII, pp. 213–321, 1861.

"Descriptions of new Cretaceous fossils from Texas," Proc. Boston Soc. Nat. Hist., Vol. VIII, pp. 188–205, 1861–1862.

"Observations on the Cretaceous strata of Texas," Texas Almanac, pp. 203–205, 1861.

Extract from a letter to the corresponding secretary of the Academy of Science of Saint Louis, read November 5, 1860; mentions the discovery of dicotyledonous leaves in the Cretaceous strata of Red River, Trans. Acad. Sci. Saint Louis, Vol. II, pp. 140, 141.

"Descriptions of new Paleozoic fossils," Trans. Acad. Sci. Saint Louis, Vol. II, pp. 108–113, 1862; describes *Goniatites Texanus*, a new Carboniferous fossil from the bluffs of Wallace Creek, San Saba County, Texas.

Communication to the Academy of Science of Saint Louis, March, 1861, announcing the apparent discovery of the Ripley group of the Cretaceous in Texas, Trans. Acad. Sci. Saint Louis, Vol. II, p. 152.

At the time of his death Dr. Shumard had in his possession many valuable notes and unpublished manuscripts concerning the geology and paleontology of Texas that would, no doubt, throw much light upon some of the important points concerning that region. Dr. C. A. White has published illustrations of some of the species[1] he described without figures, and this will probably be done in the case of others of his unfigured specimens as soon as duplicates can be collected and identified. The notes and manuscripts, however, should not be lost to science, and it is hoped that some friend of the deceased will produce them ultimately for publication.

Mr. Roessler, the topographer of the survey, has published several valuable maps, among them a large topographic map of the State, printed in 1874, embodying the plans set forth by Dr. Shumard in his report of progress.

The final remnant of the collections remained for many years in the capitol building at Austin, until the burning of that structure in 1881 completely destroyed the last trace of them.

Expense.—It is impossible to ascertain the exact cost of the Shumard survey to the State of Texas from the date of its inception, November, 1848, until the publication of Dr. Buckley's report in 1866. Dr. Buckley states that Dr. Shumard expended $28,000 during the twenty-six months of his administration, which was $8,000 in excess of the appropriation.

[1] Contributions to Invertebrate Paleontology No. 2. Twelfth Annual Report U. S. Geological and Geographical Survey of the Territories. F. V. Hayden, U. S. Geologist. Part I, Geology, Paleontology, and Zoölogy. See pp. 22, 38, 39.

The following items of expenditure are mainly compiled from Dr. Shumard's First Report of Progress, pp. 16, 17. They represent the disbursements of the first fourteen months of his administration:

Salaries: Chief geologist, at $3,000; two assistant geologists, at $1,500 each; topographer, at $600; various subordinates: aggregating	$7,195 71
Equipment (including fitting up of office, apparatus, laboratories, stables, purchase of teams, camp equipment, &c.)	4,947 62
Traveling and transportation expenses	2,845 96
Office expenses	83 71
Total expenditure	15,073 00
Deduct cost of equipment	4,947 62
Actual running expense for fourteen months	10,125 38

The expense of the continuation of the survey under the four months of Dr. Moore's administration cannot be obtained. Based upon the cost of Dr. Shumard's for a similar time they could not have exceeded $4,000, for it must be remembered that retrenchment was the watchword under which he was appointed to the directorship.

The cost of Dr. Buckley's administration for one year could not have exceeded $4,000, as he had no assistants and the State was only at the expense of his salary and the cost of publishing his pamphlet. It may be fairly estimated that the total expense of this survey to the State was less than $25,000.

THE SECOND GEOLOGICAL SURVEY (GLENN-BUCKLEY).

Since the disastrous end of the Shumard survey in 1867 little work of positive scientific value has been done by the State of Texas. When the immediate effects of the civil war had passed away and the political excitement of the reconstruction period had subsided, the expediency of reorganizing the State survey was again broached.

To distinguish it from the Shumard survey, described in the previous pages, this new organization may be called the second geological survey or the Glenn-Buckley survey. It accomplished even less than the first one.

By legislative enactment, approved August 13, 1870, the governor was authorized to appoint a State geologist, with the consent of the senate, the incumbent to give security in the sum of $5,000. The State geologist was to appoint two assistants, one of whom was to be an expert chemist and mineralogist. The duties of the survey were to make a descriptive survey of the State, and an agricultural, geologic, and mineralogic examination and classification of rocks, soils, minerals, mineral waters, fossils, &c. Rooms were to be provided by the governor for the deposit and arrangement of specimens by the geologist. A report of progress was to be made to the governor at each regular session of the legislature. The salary of the principal geologist was to be $3,000; of the principal assistants, each, $1,800, traveling and incidental expenses to be paid by the State. Appointees were required to take an oath of office, agreeing not to purchase, with the view of speculation, any landed or mining interest in the State during their term of office and not to conceal any information relative to any discovery &c. The governor was authorized to offer for sale the reports, when published, to citizens of the State, at a cost not to exceed that of publication, proceeds to be placed to the credit of the common school fund. The State geologist was allowed fifty copies for distribution to scientific men and the assistants twenty copies each. The governor was empowered to remove for neglect or malfeasance in office. All former laws were repealed.

Early in 1873 Governor Edmund J. Davis appointed John W. Glenn State geologist. In November he took the field, with Charles E. Hall as first assistant, and went into Burnet, Llano, and San Saba Counties,[1] returning to Austin in January, 1874, and soon afterwards he resigned. In view of the destruction of the archives it is satisfactory to have Mr. Glenn's direct statement regarding his connection with the survey, kindly furnished in reply to a request for it, and not without value in its bearing upon the work of others in the same field.

LETTER OF MR. J. W. GLENN.

NEW ORLEANS, LA., *August* 7, 1886.

DEAR SIR: Reply to your letter has been delayed until now from necessity of referring to the comptroller of Texas for some details of expenditures which I had forgotten.

I reply to your interrogatories in their order, viz:

1. I was State geologist for Texas from March 31, 1873, to March 6, 1874, when I resigned.
2. The expenses of my administration for that time were $3,637.34.
3. I had no predecessor; my successor was S. B. Buckley.
4. Mr. Rossiter was never State geologist. One A. B. (or A. R.) Roessler was a draftsman in the geological department in 1861 under Dr. Shumard. He was also employed in printing and distributing circulars &c. in 1875 and 10,000 copies of Texas maps in 1875.

A geological survey of Texas was authorized by law and prosecuted to some extent under Dr. Shumard, but was brought to an abrupt ending in 1861 by the war. Nothing further was done until 1873, when I was appointed under a law just then passed, which law contemplated a complete work.

The disorders of the time and want of proper appreciation of the importance of geological work on the part of the public caused me to resign, and S. B. Buckley, who in 1861 was an employé of Dr. Shumard in the division of botany, was appointed my successor. His official existence was brief and barren of scientific results. I have always regarded Roemer's report on the Cretaceous in Texas with favor, and have found that Dr. Shumard's reports, so far as they were published, agree in the main with my examinations; and Roemer and Shumard may be considered as the sole authorities on the geology of Texas up to 1873, unless we add to them part of the United States boundary report.

No publication was made of any of my reports. Before I assumed the duties of State geologist I was familiar with the area and outlines of the coast formations,

[1] First Annual Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, p. 13.

Tertiary, Cretaceous, and the Carboniferous, in the northern part of Texas. My first work was to establish a base line which would include outcroppings of the known formations. As established, this line began in Blanco County, in the Cretaceous; thence northward until it encountered the Cretaceous again overlying the Carboniferous in the north part of the State.

Between these two ends of the base line, beginning at the south end, it passed through the following formations in the order as stated, viz: Cretaceous, Carboniferous, Upper Silurian, Lower Silurian, Azoic, Lower Silurian, Upper Silurian, Carboniferous, Cretaceous.

The result was one of the most interesting I ever accomplished. Every square mile of the territory surveyed was carefully platted on the map and defined in the field, and each one numbered and worked over with great care, and the collections taken from each bore its number and from what part each came. Probably the most valuable part of my work, from an economic stand, if the report of it had only been promulgated in print, was my report on the wild sumach of Texas (*R. copallina*), from detailed analyses extending through the entire growth and determining the period of greatest economic value in tannic acid.

These analyses were made by Mr. George H. Katteyer, in the most elaborate and painstaking way, and included an amount of exact information which, owing to the vast growth of wild sumach in Texas, would have proved of immense value to her people in that new industry.

The paleontology of Texas is to me more interesting than that of any other part of the country, especially in the Carboniferous and Lower Silurian formations.

I believe I have replied substantially to all of your inquiries. If not, and you will indicate where, I will gladly supply the omission.

Respectfully, JOHN W. GLENN.

ROBERT T. HILL,

Assistant Paleontologist, U. S. G. S., Washington, D. C.

OPERATIONS OF 1874.

In March, 1874, Governor Richard Coke appointed Dr. S. B. Buckley State geologist. Dr. Buckley appointed Prof. Richard Burleson assistant geologist, Charles E. Hall subassistant, James E. Horn book-keeper and commissary, having Friench Simpson and Jack Coke as volunteer assistants without wages. Field work was begun May 11, and William D. Carrington, Ed. Shands, and a cook were of the party. Dr. Buckley says of his summer's work:

Our trip during the summer has only been a general reconnaissance or partial survey of the following counties. [Here follow the names of forty-five counties.]

No detailed surveys have been made, the object being merely to ascertain the leading geological, mineralogical, and agricultural features of the counties visited as a guide to future examinations and aid to the capitalist and immigrant.[1]

Although during a part of the time Professor Burleson traveled with a subparty over a separate route, it is clear that in covering such a scope of country the field work consisted of little more than a jaunt in an ambulance, rarely deviating from the main road.[2]

The parties traveled rapidly from day to day, gathering fossil and mineral curiosities and noting extravagant stories of agricultural possi-

[1] First Annual Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, p. 16.

[2] See The Coming Empire, or Two Thousand Miles in Texas on Horseback, by H. F. McDaniels and N. A. Taylor, New York, A. S. Barnes & Co., 1878, p. 315.

bilities by farmers along their routes. No stratigraphic or topographic work was done, nor were any barometric or other measurements made. From the first annual report of the survey, already cited, some localities can be identified, but its 142 octavo pages are essentially devoid of scientific interest. No office or laboratory work was reported.

The expenses of the half year from May 1 to November 1 are given as follows:

Camp outfit	$1,508 50
Field expenses	871 15
Help	750 00
Total[1]	3,129 65

From Mr. Friench Simpson, of Columbus, Tex., one of the gentlemen who accompanied Dr. Buckley as a volunteer assistant, I have received the following detailed account of the appropriations and expenditures of the survey for the first year of its existence:

Total amount of appropriation		$7,250 00
Salary of geologist	$3,000 00	
Office and chemical supplies	300 00	
Wood	50 00	
Books and instruments	200 00	
Traveling expenses	2,700 00	
Total expenditures	6,250 00	
		6,250 00
Returned to treasury		1,000 00

OPERATIONS OF 1875.

The work of 1875[2] was in continuance of the plan adopted the preceding year of ascertaining, by a general reconnaissance of the State, its main geologic and agricultural features.

The observations for this year were mostly made in the region west of the Colorado River and north of latitude 29°. These observations were of the same general character as those of the preceding year, except that a barometer was introduced into the survey and a few altitudes were recorded.

For an account of the expenses of this year we are again indebted to Mr. Simpson. They were as follows:

Salary of the geologist	$3,000 00
Office and chemicals	500 00
Traveling expenses	2,000 00
Postage	200 00
Fuel	50 00
Total expenses	5,750 00

[1] First Annual Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, p. 119.

[2] Second Annual Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, A. M., Ph. D., State geologist, Houston, 1876, p. 5.

At the end of the fiscal year Governor Richard Coke, who had himself appointed Dr. Buckley, being convinced that the geological survey as conducted was of no value to the State, vetoed the annual appropriation, thus terminating the survey. The two reports cited contain all the contributions made, to my knowledge, by the reorganized survey, and the State has done no work of the kind since.

RECENT MISCELLANEOUS INVESTIGATIONS.

Some additions to the geologic knowledge of Texas have been made by individual contributors.

Most of the papers contributed were only semi-scientific, written with a view to furnishing popular descriptions of the region. Many of them are now lost, owing to the destruction of the obscure mediums in which they were published.

INDIVIDUAL CONTRIBUTORS.

Previous to the civil war several gentlemen, residents of the State, contributed articles to the southern press upon these questions.

Professor Caleb G. Forshey and *George Wilkins Kendall* were among them. To secure a complete list of their writings would now be impossible, but many of them are still extant in the almost inaccessible files of New Orleans and Texas papers and in De Bow's Commercial Review.

Since the civil war not many residents of the State have contributed to its geologic literature. There have been one or two gentlemen, however, who have been interested in the geology of their State.

N. A. Taylor has contributed many articles to the press of the State, as well as written a book that contains valuable data concerning the geologic features of Texas. While his works are lacking in the exactness of detail that is necessary in scientific matter, his deductions are original and oftentimes so plausible as to seem worthy of extended development and treatment. Unfortunately most of Mr. Taylor's contributions are now inaccessible, he himself being unable to furnish a complete list of them or of their dates and places of publication. His little book[1] contains much general information of value to one who contemplates studying this region.

Ex-Governor Oran M. Roberts[2] gives much information concerning the physical geography of the State. Perhaps no other man is so thoroughly acquainted with the general topography of Texas as he. His observations are acute, but he makes no claim to modern scientific knowledge and the valuable data he gives are unaccompanied by geologic deductions.

[1] The Coming Empire, or Two Thousand Miles in Texas on Horseback, by H. F. McDaniels and N. A. Taylor. A. S. Barnes & Co., New York, 1878. 12°, 390 pp.

[2] A Description of Future Texas; Its Advantages and Resources, with Some Account of their Development, Past, Present, and Future, by O. M. Roberts, Present Governor of Texas, St. Louis, Mo., Gilbert Book Company, 1881.

W. F. Cummins has also written many valuable papers for the State press. His observations are wide, but his writings are valuable for the localities they give rather than as direct contributions to stratigraphy. Mr. Cummins has been of great service as a collector, having made Prof. E. D. Cope's vertebrate collections in Texas. A list of his sketches in periodicals is given below.[1] He has an important mass of unpublished material.

Dr. Charles A. Ashburner made an economic study of the coal fields of Northwestern Texas in 1881 on behalf of certain railroad companies. He contributed a valuable paper to the American Institute of Mining Engineers upon the geology of the region.[2]

Professor E. D. Cope has spent much time in Texas studying its zoölogy. He also studied the fossil vertebrata collected for him. Unfortunately for science, this gentleman made the stratigraphic and geographic information of secondary value, and, in addition to giving few localities, has accepted as present in Texas a geologic formation the existence of which has not been scientifically demonstrated. His brief exposition of the areal distribution of the formations[3] is one of the most valuable extant upon that subject, but it contains an interpretation from which I dissent. He says:

> To the eastward of this line [the eastern border of the Cretaceous] a belt of the Laramie extends from the northeast and terminates at the south, without continuing immediately to the west.

It does not seem to me that this is the Laramie in any sense of the word, for, although it may have been synchronously deposited it has no paleontologic or lithologic resemblance to what the great authorities on that formation have described and located as the brackish water Laramie of the West. This view is based upon my personal observation of both the true Laramie of the West and what Professor Cope terms the Laramie in Texas. It is true that both formations belong to the uppermost Cretaceous or the lowest Eocene, but I think that conclusive stratigraphic and paleontologic evidence exists to show that Professor Cope's Texas Laramie is but the southern continuation of the lignitic formation of Mississippi and Arkansas or the Eolignitic group of Heilprin.

Professor Cope has also described numerous vertebrate remains from what he terms "the Permian formation of Texas." These beds should not be confounded with the trans-Pecos Permian beds of the Messrs.

[1] "Texas geology," Galveston (Texas), Daily News, December 1, 1884. "Geology of North Texas," "Permian formation in Texas," "Tertiary coals in Texas," "Carboniferous formation in Texas," and "Artesian water on the Staked Plains;" these articles were published in the Dallas (Texas) Herald and the Galveston (Texas) News at various times. The exact dates Mr. Cummins cannot give.

[2] "Brazos coal-field, Texas," Trans. Am. Inst. Min. Eng., Vol. IX, pp. 495–506, 1880–'81.

[3] On the Zoölogical Position of Texas, by Edward D. Cope, Bulletin No. 17, U. S. Nat. Mus., pp. 5–8.

Shumard, which are now known to be late Carboniferous. Professor Cope's use of the word is not verified by stratigraphic or invertebrate paleontologic data so far published.

Professor Jacob Boll, an able Swiss zoölogist and geologist, in 1875–1880 conducted a series of explorations in Texas and published a few papers upon its geology.[1] He, with Mr. Cummins, also collected vertebrate fossils for Professor Cope. His writings were only the introduction to what promised to be valuable original contributions to the geology of Texas; but the strange fatality that has so often interposed a barrier to the completion of all thorough work in this State intervened, and he died in the field in the summer of 1880.

Walter P. Jenney contributed a short but valuable article upon the geology of the trans-Pecos region.[2]

W. H. Adams published an important paper in which he makes some generalizations concerning the coal bearing strata of the Rio Grande region.[3] His deductions concerning the age of the strata at Eagle Pass, Tex., are erroneous and misleading in that he makes it Triassic—from the lithologic appearances and from the occurrence of an ammonite resembling the genus *Ceratites*, when in reality it is the very latest of the Cretaceous, as may be seen by material in the National Museum.

Dr. R. H. Loughridge prepared for the Tenth Census a brief but valuable paper[4] on the geologic features of the State. This may be classed as one of the most important contributions to the general topography and the geology of Texas. It is accompanied by maps showing the distribution of soils &c. and by a brief geologic discussion of the whole region. It contains a comprehensive statement of the areal distribution of the geologic formations and is by far the best general paper upon the subject thus far written. Much detail is given concerning the hitherto indefinite boundary between the Tertiary and the Cretaceous, which Dr. Loughridge deflects too much to the westward south of San Antonio. He notes the occurrence of the Ripley group of the Cretaceous near Terrell, Kaufman County, and gives a list of its fossils. He also describes the character of the rotten limestone as it occurs near Clarksville, but erroneously includes in this formation the several distinct prairie regions of Central Texas. He uses Dr. B. F. Shumard's section, but his own observations are not altogether in harmony therewith. The work is chiefly valuable for the topographic information concerning the State.

[1] "Texas in its geognostic and agricultural aspect," American Naturalist, pp. 375–384, June, 1879; "Geological examinations in Texas," American Naturalist, Vol. XIV, pp. 684–686, September, 1880.

[2] "Notes on the geology of Western Texas, near the thirty-second parallel," by Walter P. Jenney, Am. Jour. Sci., 3d ser., Vol. II, pp. 25–28, 1874.

[3] "Coals in Mexico, Santa Rosa district," Trans. Am. Inst. Min. Eng., Vol. X, pp. 270, 271, 1881–'82.

[4] "Report on the cotton production of the State of Texas, with a discussion of the general agricultural features of the State," Tenth Census of the United States, Vol. V, pp. 653–831, 1884.

A. R. Roessler was the original topographer of the Shumard survey, and thus acquired a fund of geographic knowledge with which he has favored the public through the medium of several maps. One of these, printed in 1874, is by far the best contribution to a knowledge of the general surface features of the State. Mr. Roessler has published a series of county maps, giving colored areas to represent the geologic formations, but these maps are not entirely trustworthy. Mr. Roessler has also contributed several articles on the local geology.

Dr. V. Havard, U. S. A., made a most valuable contribution to the knowledge of the general topographic features of the State during 1885. Although the work[1] is primarily botanic, these topographic descriptions of a region about which so little has heretofore been known are important and far more extensive than those in some of the works giving geologic titles.

James P. Kimball, Ph. D., in an article on the geology of Western Texas,[2] discusses the orologic and paleontologic relations of the trans-Pecos country and corrects several errors in the writings of earlier travelers. He describes the peculiar metamorphic formation capping the Cretaceous strata of the region, termed *cantera*, and shows its local variations. The extension of the Texas Cretaceous formation into Mexico is also described. It is one of the most valuable of the very few articles on the region of which it treats.

Charles D. Walcott is the only representative of the scientific corps of the U. S. Geological Survey who has as yet published any results upon the Texas region founded upon personal observation. He visited the Paleozoic rocks of Central Texas in 1884 and published a short paper on them the same year, entitled "Notes on Paleozoic rocks of Central Texas."[3] This article, although brief, ranks in the same category of original investigation as the works of Shumard and Roemer. It contains the following results: Additional data on the Potsdam section and fauna; the Silurian section and fauna; the geologic relations of what has long been known as the Archaic region and its first reference to the Cambrian; and the determination of the age of the granite of Burnet County.

There are several writings upon Texas geology by gentlemen who have not visited the State that deserve mention. Of this number, few have dealt with other than isolated paleontologic descriptions of fossils, and it is of the latter class that it is proper to insert here a few remarks. Paleontology as a science is inseparable from stratigraphy. When they are divorced, paleontology becomes a misnomer for what more

[1] "Report on the flora of Western and Southern Texas," Proc. U. S. Nat. Mus., Vol. VIII (1885), Nos. 29–30, pp. 449–533, Washington, 1885.

[2] "Notes on the geology of Western Texas and of Chihuahua, Mexico," by James P. Kimball, Ph. D., Am. Jour. Sci., 2d ser., Vol. XLVIII, p. 379, 1869.

[3] Am. Jour. Sci., 3d ser., Vol. XXXVIII, pp. 431–433, 1884.

properly deserves the title of systematic or descriptive zoölogy. It is to be regretted that only three invertebrate paleontologists—Drs. Ferdinand Roemer, Benjamin F. Shumard, and C. D. Walcott—have visited the State.[1] The innumerable descriptions of new species of "Cretaceous" and "Tertiary" fossils from Texas that have adorned the annals of the scientific literature of our country for many years will have little value to science until the fossils are studied upon the ground and their proper stratigraphic position is ascertained.[2]

Dr. Samuel George Morton[3] was the first to make allusion to the Cretaceous strata of Texas. He describes, from the "Calcareous platform of Red River," the fossil *Gryphæa Pitcheri*, now accepted as the most characteristic fossil of the typical Texas Cretaceous. This locality, we can only surmise, was the same as that now called the Staked Plains region of Texas. The specimens were collected by Army officers.

F. B. Meek has contributed very little to the number of new species from Texas, but he has made an earnest endeavor to correlate the Cretaceous strata of Texas with those of the other kindred areas of this country.[4]

Dr. C. A. White has not at this date (December 31, 1885) visited the State, but he has published several papers on the paleontology of Texas, as well as figured many of the species described, but not illustrated, by Dr. Shumard. He has also figured and described several new and distinct species and printed lists of fauna from characteristic localities.[5]

---

[1] Since writing the above, Mr. T. A. Aldrich, Dr. C. A. White, and others have done some valuable work in Texas.

[2] "Descriptions of new Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils collected in Nebraska by the exploring expedition under the command of Capt. Wm. F. Raynolds, U. S. Topographical Engineers, with some remarks on the rocks from which they were obtained," Proc. Acad. Nat. Sci. Phila., Vol. XIII, pp. 415–447, 1861.

[3] Synopsis of the Organic Remains of the Cretaceous Group of the United States; by Samuel George Morton, M. D., Philadelphia, 1834.

[4] A Report on the Invertebrate Cretaceous and Tertiary Fossils of the Upper Missouri Country, by F. B. Meek. Report of the U. S. Geological Survey of the Territories. F. V. Hayden, U. S. Geologist in Charge, Vol. IX, Washington, 1876.

[5] Dr. White's writings on Texas geology are here given for the convenience of those who may be interested, because they are not noted in the existing paleontologic check lists, which were printed before his articles were written:

"Report on the paleóntological field work for the season of 1877," Eleventh Annual Report of the U. S. Geol. and Geog. Surv. Terr., for 1877, pp. 159–320, 1879. Describes several new species of fossils from the Cretaceous strata of Texas.

"Descriptions of new Cretaceous fossils from Kansas and Texas," Proceedings of the U. S. National Museum for 1879, Vol. II, pp. 292–298.

"Report upon the Invertebrate Fossils collected in Portions of Nevada, Utah, Colorado, New Mexico, and Arizona, by Parties of the Expeditions of 1871, 1872, 1873, and 1874," in Report upon the Geographical and Geological Explorations and Surveys West of the One Hundredth Meridian, in charge of First Lieut. Geo. M. Wheeler, *Prof. Angelo Heilprin* has published a valuable compilation of the observations that have been made upon the Tertiary geology of the State in his work entitled Contributions to the Tertiary Geology and Paleontology of the United States, printed at Philadelphia in 1884. Besides being a compilation of previous research, the observations and the deductions of Professor Heilprin therein expressed are of great value. He has, besides, described several species from the Tertiary of the State.

The writings of Messrs. James Hall, Conrad, and Gabb have been referred to in the preceding pages in connection with the expeditions upon which the fossils and other specimens were collected. They also made a few individual contributions. The true horizon of the species cannot be known until further stratigraphic observations are made.

WORK OF THE U. S. GEOLOGICAL SURVEY.

This narration of the geologic work accomplished in Texas practically closes at the date when the U. S. Geological Survey was authorized to carry its work into the States (1884), although I have included some work done by C. D. Walcott, thus extending the narrative to December 31, 1885. The date at which the U. S. Geological Survey was enabled to extend its operations into the States is one of the most important in our scientific history, and to the State of Texas it will prove of especial consequence. The era of hasty reconnaissance and poorly published results may be considered ended and the work

Corps of Engineers, U. S. Army, Vol. IV, Part I, Paleontology, pp. 1–219. 4°. Washington, 1875. Gives lists of fossils from Cretaceous localities in Texas.

"Conditions of preservation of invertebrate fossils," in Bull. U. S. Geological and Geographical Survey of the Territories, Vol. V, article VII. Describes characteristic condition of preservation of fossils from the Cretaceous rocks of Texas. Washington 1879.

"Descriptions of new Cretaceous invertebrate fossils from Kansas and Texas." Proc. U. S. National Museum, Vol. II, pp. 292–298, Plates I–IV.

"Contributions to invertebrate paleontology No. 1: Cretaceous fossils of the Western States and Territories," in Eleventh Annual Report U. S. Geological and Geographical Survey of the Territories [for the year 1877], pp. 273–319, Plates I–IX. Washington, 1879. Describes a few fossils from the Cretaceous of Texas.

"Contributions to invertebrate paleontology No. 2: Cretaceous fossils from the Western States and Territories," in Twelfth Annual Report of the United States Geological and Geographical Survey of the Territories [for the year 1878], pp. 1–38; Appendix, pp. 38, 39, Plates XI–XVII. Washington, 1883.

Notes on the Mesozoic and Cenozoic Paleontology of California. U. S. Geological Survey Bulletin 15, Washington, 1885. Describes the westward extension of fossils common to Texas.

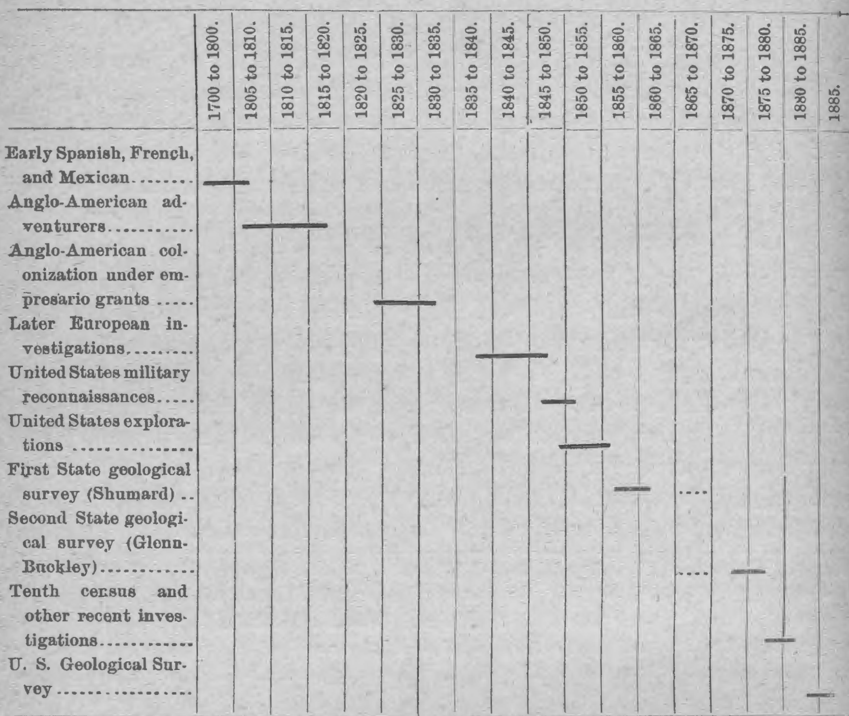
"On Mesozoic Fossils. Description of certain aberrant forms of the Chamidæ from the Cretaceous rocks of Texas." U. S. Geological Survey Bulletin No. 4, Washington, 1884.

"A review of the fossil Ostreidæ of North America; and a comparison of the fossil with the living forms," in Fourth Annual Report of the U. S. Geological Survey, pp. 273-333, Plates XXXIV–LXXXII, Washington, 1884.

of thorough scientific exploration will be continued under more adequate methods. Already several sheets of the topographic map have been issued.[1]

SUCCESSION OF SCIENTIFIC EXPLORATIONS.

Diagram of succession of eras of scientific explorations in Texas.



[1] Respecting the methods of the U. S. Geological Survey in making maps, see Annuaire géologique universel, tome II, 2e partie, appendice, Paris, 1886: Méthodes de cartographie géologique employées par l'United States Geological Survey, presented at Berlin by W J McGee.

II. SUMMARY OF RESULTS.

TOPOGRAPHY.

It is plain that the scientific investigations heretofore made in the State of Texas have been elementary and fragmentary in character. Especially does this become apparent when we contrast the small amount of work done with the size of the State. For instance, strata of the Cretaceous period are found near both Texarkana and El Paso, although these cities are nearly eight hundred miles apart; but not a line is published noting a single dissemblance between the stratigraphic and the zoölogic features of this formation between these two places, except the confessedly limited observations of Roemer, Marcou, Shumard, Schott, Parry, and Marcy. The contributions of others, especially those of a paleontologic nature, will remain unavailable until further verification. Many of the paleontologic descriptions of species are even without any locality, much less any detailed assignment to a stratigraphic horizon, and nothing has been done in the direction of tracing faunal or specific range and variation. For the stratigraphy even less can be said than for the paleontology, although a few sections of great value have been presented. It must be said, however, that stratigraphic work has been peculiarly neglected in this State. Even Roemer's great work, the best ever printed on the geology of Texas, does not give a single stratigraphic section, and we find extending through its otherwise almost incomparable pages a fundamental stratigraphic error whereby the value of the whole is impaired.[1]

The topography of the State, excepting the limited portion covered by the recent operations of the U. S. Geological Survey, is poorly delineated. The slope of the surface, the directions of the streams, and the principal forest regions were known in a general way to the Spaniards long before the present century and were crudely delineated by Humboldt in 1804. The development of detail and the delineation of these features upon successive maps until the present time have been successively expanded and recorded by Kennedy, Roemer, and other individuals, the various land locating parties, railroad surveys, and military expeditions. The finer points of inland topography,[2]

[1] Roemer thought that the Cretaceous formations at the foot of the highlands between New Braunfels extended beneath instead of resting unconformably upon them.

[2] The U. S. Coast and Geodetic Survey has carried its work along the immediate coast line of the State.

such as triangulation, determination of altitudes, meandering of streams, &c., have never been attempted until the recent operations by the U. S. Geological Survey, and even the coarser topographic features have not been correctly presented. For instance, it is utterly impossible at this writing to obtain an idea of the trans-Pecos mountain systems, and no map makes a distinction between the hills or buttes east of that region and true disturbed mountain ranges. The chief defect in our topographic knowledge of the State is incident to the fragmentary manner in which the same has been collected, no attempt having ever been made by the State of Texas to make a systematic map of its territory.[1]

The most accurate description of the topographic features is that of Loughridge, 1884, but even this fails to classify the natural divisions in a comprehensive manner. He says:[2]

In the State of Texas we find combined a great diversity in both soil and topography; * * * in topography, from the extreme of low and flat prairie lands and a very little marsh along the coast, by gradual transitions and elevations, to the chains and peaks of mountains on the far west [southwest], whose summits are 5,000 feet or more above the sea.

* * * * * * *

Several of the great agricultural regions that form so prominent a feature in the other Southern States have their termini in Texas, and are cut off on the southwest either by the prairies of the coast or by the great mesquite and cactus chaparral prairies of the Rio Grande region, or they abut against the eastern bluffs of the plains.

The coast of Texas * * * is here bordered by an almost continuous chain of islands and peninsulas (the latter having the same trend as the islands). * * * The large estuaries that have been formed at the mouths of the streams, except the Sabine, the Rio Grande, and those of the Brazos section, form another feature peculiar to the Texas coast. The border lands of these estuaries are usually high, their almost vertical clay bluffs being washed by the waters of the bay, and the open prairies of the uplands often extend to their very edge.

Mr. Gannett estimates the water area of the coast, bays, gulfs, &c., to be 2,510 square miles and that of the rivers and lesser streams at about 800 square miles.

A general view of the State, as presented in two cross-sections, presents the following features:

1. *Along the Louisiana line.*—From the mouth of Sabine River northward we find at first a small area of marsh lands, terminating the marsh region of Louisiana, and not occurring to any extent westward. Passing these, we come to the long-leaf pine flats, extending westward only to the Trinity River, and being also the western ter-

[1] The map representing the physical geography of Texas more minutely than any other is entitled "A. R. Roessler's latest map of the State of Texas, exhibiting mineral and agricultural districts, post-offices and mail routes, railroads projected and finished, timber, prairie swamp lands, &c. Authorities: Official maps of the United States and Texas State General Land Offices, surveys and reconnoissances of the U. S. Coast Survey, the various railroad surveys, U. S. Mexican Boundary Commission Surveys, U. S. Engineer Dept., and other authentic materials, compiled and drawn by M. Y. Mittendorfer, C. E., 1874." Much of the excellent detail of this map was evidently made from data collected by the Shumard survey, of which Mr. Roessler was topographer.

[2] Tenth Census: Report on Cotton Production in the United States. Report on the Cotton Production of the State of Texas, Part I, pp. 653-831.

minus of the belt that extends across all of the Gulf States, the lower part of Florida, and along the Atlantic coast through North Carolina. Its surface in Texas is quite level northward for about 50 miles, when the more undulating or rolling pine hills are reached, which also form a border to the pine flats just mentioned across the southern Gulf States. Thence northward to Red River the country is rolling and hilly, and is covered with oak, hickory, and short-leaf pine—a region that extends eastward through Louisiana, Arkansas, and the northern part of Mississippi into Tennessee. This region passes southwestward, becoming more and more narrow, until it tapers off to a point 100 miles from the Rio Grande, and also includes the belt of the red Tertiary hills of the other States that probably terminates on the southwest in Guadalupe County.

2. *From the coast in a northwest and west direction.*—The mainland coast of Texas presents a very irregular outline, with its many bays, peninsulas, and islands, and but a small proportion of the mainland reaches the waters of the Gulf. As before stated, there is scarcely any marsh land on the coast west of the Sabine marshes.

For a distance of from 50 to 100 miles inland from the coast the country is very level, with open prairies, whose continuity is broken only by the timbered streams, with occasional strips or "motts" or clumps of timber, and by the broad and heavily timbered alluvial or "sugar bowl" region of the Brazos.

The rise, slight and very gradual inland from the coast, is almost imperceptible for many miles, when the country becomes undulating and then rolling, and the prairies give way to the more or less broken and hilly oak and pine uplands, which cover all of the northeastern part of the State, as already mentioned. The country rises rapidly to the north and northwest, reaching an elevation of several hundred feet along the western edge of the timbered region, and is interspersed throughout with small "brown loam prairies." Leaving the timber lands and continuing northwest we find a region of "black waxy prairies," underlaid by the Cretaceous "rotten limestone," extending southwest to San Antônio and thence west to the foot of the plains. Northward this region passes through the southern part of the Indian Territory into Arkansas. These prairies are at first, on the east, rather level, or at most undulating, with an altitude of 500 or 600 feet, but westward become more rolling, hilly, and broken, until finally, on their western limits, high and bald hills and peaks stand out in bold relief at an elevation of nearly 1,000 feet above the sea. The monotony of these interior prairies is broken by the timbered streams and on the north by the wide belt of "lower cross timbers," which reaches from the Red River to the Brazos in an almost due south course. Otherwise there is very little timber to be seen.

At the western edge of the northern half of the black prairie region there is another belt of cross timbers,[1] interspersed with small, black, Cretaceous prairies, very irregular in outline and in width, and beyond it is the broad red-loam and partly timbered region, comprising high ridges, mesquite prairie valleys, and broad tablelands, the country gradually rising to the foot of the high plateau of the Llano Estacado, several thousand feet above the level of the sea. This region terminates on the southwest against the bluffs of the plains south of the Llano Estacado, and a large area penetrates southeastwardly almost across the black prairie region.

On the northwest there is a large, extensive region, lying wedge shaped, with its point south, between the red loam lands and the Llano Estacado, and comprising the great gypsum lands of the State, with high and rolling prairies, whose uplands are largely destitute of timber.

To the westward the broad, level, and bare plains of the Llano Estacado occupy a terrace with abrupt bluffs on the north, some 200 feet above these regions, and with a gentle rise pass out of the State into New Mexico on the west and to the mountains on the southwest. Deep cañons have been cut into the eastern part of this plateau

[1] Mr. Loughridge places this edge of the black prairie too far west. It ends at the eastern edge of the lower cross timbers.

by the headwaters of the large rivers of the State, but to the west there is only a vast, treeless plain, more or less undulating, with a few low but prominent sand hills and ridges.

On the extreme west, between the Pecos and the Rio Grande, the country reaches its maximum height, with several chains of almost treeless mountains rising several thousand feet above the general level, and separated from each other by broad and level plains 20 or 30 miles in width and almost destitute of vegetation. These mountain ranges enter the State from New Mexico. Southward the plains extend along the Rio Grande to a point a little south of its junction with the Pecos. Thence to the Gulf are broad and high prairies, broken by deep arroyos or ravines, and with little growth other than occasional live oak trees and great chaparrals or thickets of thorny shrubs.

CLASSIFICATION OF TOPOGRAPHY OF TEXAS.

For convenience of discussion I broadly classify the general topography of Texas as follows:

First. The coastal plain, representing the continuation of the topographic features of the other Gulf States, so far as they represent the sedimentation of the former waters of the Upper Cretaceous outlines of the Gulf of Mexico, the topographic and geologic boundaries coinciding. In Texas this approximately coincides with a line drawn concentric with the Gulf coast about 200 miles inland.

Second. The black prairie region, a triangular area immediately succeeding the foregoing to the west. It is also a southern continuation of similar topographic and geologic features of Arkansas, Mississippi, and Alabama. Its western boundary extends from Eagle Pass via Austin to Denison, on Red River. It is a level or gently undulating prairie, with a general slope to the southeast and an altitude of from 500 to 750 feet. The underlying strata are uniformly Cretaceous and of a horizon that will be described elsewhere.

Third. The central or denuded region, embracing all the country between the escarpment of the plains and the black prairie region and north of the hydrographic basin of the Colorado. This region comprises a number of geologic formations and is between 600 and 2,000 feet in altitude.

Fourth. The plateau region, comprising the Llano Estacado. It is a continuation from the northward of the topographic and geologic features of the great plains along the eastern slope of the Rocky Mountains.

Fifth. The mountainous or trans-Pecos region. This consists of the country in Texas and Northern Mexico adjacent to the disturbed area of the southern or southeasterly prolongation of the Rocky Mountains. It is chiefly west of the Pecos, in Texas, but crosses into Mexico west of that river, again recrosses the Rio Grande east of it near Eagle Pass, and continues until a few miles south of Laredo.

Each of the areas has a well marked individuality, although the boundaries between them cannot always be closely defined.

Chart illustrating the progressive classification of the topographic features of Texas.

Kennedy, 1841.	Ferd. von Roemer, 1848.	R. H. Loughridge, 1884.	Classification used in this work.	
The level region.	The level region (niedriges, flaches Land).	Southern and coast prairies. Gray silt and pine lands. Sea marsh. Oak, hickory, and pine region. Brazos delta and other alluvial lands.	(1) The coastal plain. Pine lands. Pine, oak, and hickory lands. Prairies of East Texas. Coast alluvium. Southwestern prairies.	Continuation of salient topographic features of coast plain of Louisiana, Arkansas, Mississippi, Alabama, &c.
Rolling or undulating region.	Hill land, or rolling or undulating region (sanftwelliges Hügelland).		(2) Black prairie region.	Continuation of black prairie regions of same States, except Louisiana.
	Highlands (das zum Theil felsige Hochland).	Central black prairie region. Cross timbers. Sand hills and metamorphic lands of Central Texas. Northwestern red loam prairies and timber lands. Gypsum prairie region.	(3) Central or denuded region. Cross timbers. Coal Measures. Grand prairie. Butte districts. Hamilton County prairie. Granite region. Gypsum lands. Red prairies.	Peculiar to Central Texas and southern part of Indian Territory. Terminates west of San Antonio before reaching Rio Grande.
Mountainous region.	Steppen-Lande.	Llano Estacado (table lands and sand hills).	(4) Plateau or Staked Plains region.	Southern continuation of Great Plains at eastern foot of Rocky Mountains, British America to Southern Texas.
		Plains with granitic mountains and probably "sand" desert of Rio Grande.	(5) Mountainous or trans-Pecos region. West of Pecos River and Lower Rio Grande, between Eagle Pass and Laredo.	Southeastward deflection and continuation of mountain region of New Mexico.

HISTORIC GEOLOGY AND STRATIGRAPHY.

In the following table are given, from the writings already mentioned, the members of the geologic series that have been reported from Texas. The authority for some of these groups is slight and untrustworthy, but nevertheless they have been thus published. Many of the subdivisions are synonyms of different authors, which will require extensive field work for positive identification and correlation.

Geologic formations reputed to occur in the State of Texas, with authorities.

Era.	Period.	Subperiod.	Local formations.	Reported occurrence in topographic area—
Cenozoic.	Quaternary	Recent[1]	Alluvium[1]	1
			Diluvium[1]	1
	Tertiary.		Grand Gulf[5]	1
			Mauvaises Terres[4]	1
			Vicksburg[7]	1
			Claiborne[1]	....
Mesozoic.	Cretaceous.	Senonian[1]	*Laramie,*[6] Eolignitic[7]	1 and 2
			Kreide des Hochlandes[1]	2
			Comanche Peak group[4]	3
		Senonian[2]	Washita Limestone[2,3]	3
		Turonian[1]	Kreide am Fusse des Hochlandes[1]	2
			Ripley group[4,5], Austin Limestone	2
		Greensand[3]	Rotten Limestone[5]	2
			Dakota Sandstone[4]	2 or 3
		Neocomian[3]	Washita Limestone[3]	3
			Comanche Peak group[3]	3
	Triassic and Jurassic.	*Jurassic*[3]	*Washita Limestone*[3]	3
			Comanche Peak group[3]	3
			Staked Plains[3]	....
		Triassic[3]	Gypsum region[3]	3 and 4
		Jura-Trias[2]	*Red beds*[6]	3
		Permian[2,6]	*Upper Carboniferous*[2]	....
Paleozoic.	Carboniferous.	Permo-Carboniferous	Upper Carboniferous[8]	3
		Permian[2,6]	Trans-Pecos region	5
		Upper Carboniferous	Central region[9] Trans-Pecos region[8]	3 and 5
		Sub-Carboniferous[9]	*Brazos Coal Field*[9]	3
	Devonian.	*Devonian*[9]	Central region	3
	Lower Silurian.	Cincinnati[3]	....	3 and 5
		Chazy[3]	....	5
		Calciferous[10]	....	3 and 5
	Cambrian.	Potsdam[10]	....	3 and 5
	Pre-Cambrian.	Llano[10]	....	3
		Archean[1]	....	....
		Azoic[1]	....	....

NOTE.—Authorities: [1] Ferdinand Roemer; [2] G. G. Shumard; [3] Jules Marcou; [4] B. F. Shumard; [5] R. H. Loughridge; [6] E. D. Cope; [7] Angelo Heilprin; [8] James Hall; [9] C. A. Ashburner; [10] C. D. Walcott. Names of local formations, in italic, as applied by the writers referred to are no longer accepted.

SO-CALLED ARCHEAN AND EARLIER PALEOZOIC STRATA.

The older rocks of the geologic series are found in both the central and the trans-Pecos area, but they have been studied chiefly in the former and little or nothing is known of their exact occurrence in the latter.

A few miles south of the present geographic center of the State, in the counties of Mason, Llano, Burnet, and San Saba, is an outcrop of so-called Archean and earlier Paleozoic rock. This region was known to the Spaniards and was evidently considered by them of much mineral importance. Kennedy[1] first intimated its geologic age and Roemer was the first to give an intelligent description of it. Dr. B. F. Shumard confirmed Roemer's work, but its true stratigraphic relations were not understood until lately studied by C. D. Walcott, of the U. S. Geological Survey. Of these Paleozoic strata Mr. Walcott says:[2]

> At all localities where the base of the Potsdam was observed it rests *unconformably* on a great formation that is stratigraphically the equivalent of Powell's Grand Cañon series (Grand Cañon and Chuar groups).[3] In the Grand Cañon of the Colorado the latter are overlaid by the Tonto group, a series of rocks in both lithologic and paleontologic characters singularly like the Texas Potsdam group.
>
> For this series of pre-Potsdam strata the local name of Llano group is proposed, from the best exposures of the group occurring in the county of Llano. Outcrops also occur in Burnet, Mason, San Saba, Blanco, and Gillespie Counties.

Mr. Walcott speaks of "extrusions of granite at or near the close of the erosion of the Llano group and before the deposition of the Potsdam," and says further: "It is to this age that the great masses of granite observed in Western Burnet and all through Llano County belong." The early students of these strata supposed that the outcrops of eruptive and granitic rocks were Azoic or Archean, and that they were the base of the entire series. Mr. Walcott showed that there are no rocks there exposed of the undoubted Archean and that the granites before referred to that era were not fundamental, but extrusive, and since his deductions are based upon more careful stratigraphic study

[1] Texas: The Rise, Progress, and Prospects of the Republic of Texas, Vol. I, pp. 114 et seq.

[2] "Note on Paleozoic rocks of Central Texas," Am. Jour. Sci., 3d ser., Vol. XXVIII, pp. 431–433, 1884.

[3] In a later paper Mr. Walcott refers these groups to the Keweenawan, and says: "The Keweenaw system is here used to include the Keweenaw series of the Lake Superior region, the Llano series of Texas, and the Chuar and Grand Cañon series of the Grand Cañon of the Colorado, Arizona, and is considered of equal value with the Cambrian, Lower Silurian (Ordovician), Upper Silurian, and other systems of the Paleozoic rather than the Archean. It may be that the Keweenaw and Grand Cañon series belong to distinct systems of strata, but until this is proven I prefer to provisionally refer them to the pre-Cambrian, post-Huronian system. I think the Grand Cañon and Llano strata belong to one system."—"Classification of the Cambrian System of North America," Am. Jour. Sci., 3d ser., Vol. XXXII, pp. 138–157, 1886. The extract forms a note on p. 153.

than those of his predecessors they are more trustworthy. According to him these earlier Paleozoic rocks consist of the following:

(1) *The Llano group.*—Alternating beds of shale, sandy shale, sandstone, limestone, and schists; thickness not determined, but probably over 2,000 feet; continuity broken by extrusive sheets of granite of pre-Potsdam origin; stratification disturbed by movement at the close of the Paleozoic, whereby the dip increases from 10° at the north end of the ridge to 40° at the south end; strike, eastward; unfossiliferous.

(2) *The Potsdam group.*[1]—Consists of massive sandstone, limestone, and Potsdam sandstone, marked by abundant Upper Cambrian (Potsdam) fauna.

(3) *The Calciferous group.*—Lower Silurian, with its characteristic fauna.

(4) *The Carboniferous group*, which was not here studied in detail.

From the observations of Mr. Walcott it is evident (*a*) that there are no Archean exposures yet known in Central Texas (this being the only Paleozoic region yet studied); (*b*) that the pre-Potsdam, the Silurian, and the Carboniferous groups are represented; (*c*) that the Devonian is absent; (*d*) that the age of the so-called Archean granites is Paleozoic; (*e*) that there were two well marked epochs of disturbance, one after the close of the sedimentation of the Llano group and the other near the close of the Paleozoic; (*f*) that the Llano group is the equivalent of the Grand Cañon and Chuar groups of Powell, and hence at the time of their deposition the sedimentation was continuous to the westward of the Grand Cañon.

The Paleozoic strata, excepting the Carboniferous, have only a limited outcrop in Texas, so far as has been discovered. The disturbed areas of the Wichita Mountains, in the southwestern corner of Indian Territory, theoretically present every favorable condition for the presence of similar exposures, but no evidence of their existence has been reported, except the similarity of their granitic structure.[2]

The large trans-Pecos disturbed mountain area also presents exposures of early Paleozoic strata, as has been reported by G. G. Shumard, Jenney, Kimball, and members of various government expeditions. Concerning the occurrence of the Lower Silurian in that region, Dr. G. G. Shumard said of the valley of the Rio Grande above El Paso:[3]

> The limestone of the Lower Silurian system is seen strongly upheaved against the western base until we reach a point ten or eleven miles north of the place where it was first discovered, when it disappears and is succeeded by strata of the Carboniferous system, which are exposed in places to the thickness of about three hundred feet. Against the western declivity, El Paso Mountains, the limestone strata are strongly upheaved, and where it is in immediate contact with the eruptive strata it

[1] Well described by B. F. Shumard, Am. Jour. Sci., 2d ser., Vol. XXXII, pp. 213-221, 1861.

[2] See numerous references in Exploration of the Red River of Louisiana in the year 1852, by Randolph B. Marcy, 1854.

[3] Trans. Acad. Sci. St. Louis, Vol. I, p. 288.

is highly metamorphosed. I was much interested by finding here, near the base of the exposure, well marked strata of the inferior Silurian system, corresponding in age to the blue limestone of Cincinnati and the Hudson River group of the New York series. The following fossils were procured from these beds: *Orthis testudinaria* Dalman, *O. occidentalis* Hall, *Rhynchonella capax* Conrad, *Rhynchonella* (a species of the blue limestone of Cincinnati), *Streptalasma cornicula?* Hall, and columns of crinoids.

Every reason exists for the supposition that the Cambrian strata are exposed there, but no surveys of the region have been made.[1] Walter P. Jenney[2] gives a section of the rocks north of El Paso, two miles, in the Organ Mountains, and recognizes there the following formations in descending series: Carboniferous, or Niagara, deposited unconformably upon a coarse conglomerate, which he thinks probably equivalent to the Oneida conglomerate of New York; gray limestone of the Hudson period; black limestone representing the Trenton, the Chazy, the Calciferous sand rock, and the Potsdam. He finds similar rocks in the Hueco Mountains, twenty miles north of the Organ Mountains, and concludes that "the greater part of the Upper Silurian and the whole of the Devonian periods are unrepresented in the rocks of Western Texas." He notes an immense development of the Carboniferous strata in the Sacramento and the Guadalupe Mountains, and of syenite at Los Cornudos. He also gives a section of the Llano Estacado as exposed at Castle Cañon and affirms their Cretaceous age; the highest he makes the Caprina Limestone of Shumard. He erroneously concludes that the denuded Cretaceous buttes east of the plains almost as far as Austin "were islands in the sea which produced the denudation, their tops showing no evidence of having ever been submerged, and in some cases wave worn cavities extend at the same height along their sides.[3]

CARBONIFEROUS SYSTEM.

The absence of the Devonian from the stratigraphic series in Texas has been noted, first by Roemer and later by Walcott and others. Dr. S. B. Buckley asserts in one of his reports that Dr. B. F. Shumard had previously announced the occurrence of the Devonian strata in Texas, but I have failed to find such a statement in any of Shumard's publications. If the Devonian is not represented, then it is evident that the Carboniferous strata are next in order after the Silurian. This fact was demonstrated by Roemer, who first noted the positive occurrence of the Carboniferous strata in Texas resting upon the older rocks along the San Saba River. He formed no idea of the extent of these rocks, however, and was not aware of their great development northward.

It is now evident that there are two widely separated areas of the Carboniferous strata in Texas, each of which has well marked individ-

[1] C. H. Hitchcock's geological map of the United States gives a large Cambrian area in the trans-Pecos region of Texas.

[2] "Notes on the geology of Western Texas near the thirty-second parallel, by Walter P. Jenney," Am. Jour. Sci., 3d ser., Vol. VII, pp. 25–28, 1874.

[3] These buttes are the remnants of subaërial erosion entirely.

uality. These I will describe separately under the names of the Central Carboniferous area and the trans-Pecos Carboniferous area.

The central Carboniferous area.—This is a comparatively narrow but elongated area of exposures, continuing from Indian Territory, between the ninety-eighth and the one hundredth meridian. Its eastern border is limited by the upper cross timbers. The extent of this area in Texas is some two hundred miles north and south between the Colorado River and the Red River. Geologically it may be said to extend along the axis of greatest denudation from the point of greatest disturbance, in Llano County, to the connection with the great Missouri coal field in Indian Territory. The latitudinal development of exposures is of varying width, owing to the irregularity of the denudation of the superincumbent Cretaceous strata, and other causes. The exposure widens, however, towards its southern base. At no place does it exceed one hundred miles in width. Exposures have been noticed in Young, Jack, Montague, Stephens, Shackelford, Palo Pinto, Baylor, Wise, Coleman, Brown, Comanche, Runnels, McCulloch, Tom Green, and San Saba Counties. Its exact boundaries are unknown. The exposures of these strata are the result of denudation of the Cretaceous, which once covered them entirely, and I have noted on the preceding pages the history of the discovery of this area. Dr. Roemer's determinations were based upon stratigraphic and paleontologic data and he did not discover the existence of bituminous coal. Various Army officers have noted the occurrence of coal to the northward, but it was first clearly described by Dr. G. G. Shumard in his remarks accompanying Marcy's report on the exploration of the Red River of Louisiana (1854). Mr. Jules Marcou the next year contributed much toward a knowledge of the geologic and stratigraphic relations and in subsequent maps intimated the continuity of the Young and San Saba County areas. Dr. B. F. Shumard, as State geologist (1858), was the first to demonstrate in the field the actual continuity of the two regions, concerning which he contributed nearly all we know. The local occurrence and the general extent having been proved by these earlier reconnaissances, there still remains much to find out concerning nearly all the geologic data of the region. Prof. C. A. Ashburner, of Pennsylvania, in a study of the northern portion of these coal fields in 1879, made the following section of the strata in the vicinity of Fort Belknap, Young County:[1]

	Feet.
Sandstone and conglomerate	40
Coal	1
Sandstone and shale	12
Coal	1
Sandstone and shale with occasional beds of limestone	15
Belknap coal bed	2½ to 4
Sandstone and shale	12

[1] "Brazos coal-field, Texas," Trans. Am. Inst. Mining Eng., Vol. IX, p. 497, 1880–'81.

	Feet.
Coal	1
Gray slate	10
Sandstone	25
Brazos coal bed	4 to 6
Gray limestone	150

From the above section he made the following deductions:

This succession of the strata is not unlike that to be found in many localities where the Carboniferous rocks are found in the Middle States. It seems to point clearly to the conclusion that the top sandstone and conglomerate is the representative of the Carboniferous conglomerate or Millstone Grit; that the limestone is the sub-Carboniferous or Mountain limestone, known generally throughout the Mississippi Valley as the Saint Louis or Chester limestone, and that the included Coal Measures are really subconglomerate.

His final conclusions are summed up at the close of the paper just quoted as follows:

The Brazos coal field is the southwestern limit of the Missourian or fourth bituminous coal basin of the United States. The Coal Measures of Stephens and Young Counties belong to the Carboniferous age. The coal strata proper are 85 feet thick, and are included between an upper sandstone and a conglomerate, representative of the Millstone Grit or Pottsville conglomerate No. 12 of the Pennsylvania series, and a lower gray limestone, representative of the Mountain limestone or Chester and Saint Louis limestone of the Mississippi Valley. The coal strata contain two coal beds of workable thickness. The upper bed, named Belknap, ranges from 2½ to 4 feet; and the lower, named Brazos, from 4 to 6 feet. The coals are high in ash and sulphur, but have never been thoroughly tested. The Brazos bed underlies a great area and will no doubt prove to be a valuable commercial coal in some localities.

The southern portion of these central exposures has not been so well studied, and we have nothing but analogy from which to infer[1] that there they are practically the same, except that the carbonaceous layers in that region become almost if not quite extinct.

Dr. Buckley reports coal from this southern region, but he was not an authority on the subject of coals, not having had a clear idea of the distinction between the true coals of the Carboniferous and later Western formations and the lignite of the Mississippi area, which is known to occur in near proximity.[2]

The trans-Pecos Carboniferous area.—Along the disturbed axes of the trans-Pecos mountainous region extensive beds of limestone have been frequently noted by reconnoitering parties. The knowledge of the topography of this area is very limited, and, this being true, it is evident that little can be known of the distribution of the geologic formations. That Carboniferous rocks occur in this region has been recorded by many observers, but very little is yet known of their true nature, except that they usually consist of massive limestone, are barren of coal seams, and that they occur along the disturbed and denuded mountain re-

[1] "Brazos coal-field, Texas," Trans. Am. Inst. Mining Eng., Vol. IX, p. 506, 1880–'81.

[2] See discussion of coals, First Report of Progress, Geological and Agricultural Survey of Texas, B. F. Shumard, State geologist, Austin, 1865.

gions. These rocks are probably a continuation of the New Mexican Carboniferous, as has been noted by Marcou and others.[1]

Two expeditions have supplied some details concerning this region, but our knowledge of it is still very general. One expedition recorded the Carboniferous as it occurs near the Rio Grande, the other as it occurs approximately along the thirty-second parallel. The observers were Dr. C. C. Parry,[2] of the Mexican boundary survey, and Dr. G. G. Shumard,[3] of Capt. John Pope's expedition for boring artesian wells in the Great Plains. The collections of both of these gentlemen fell into the hands of good geologists, and reports were written upon them by Prof. James Hall[4] and Dr. B. F. Shumard,[5] respectively.

Dr. Parry, in his remarks,[6] gives the following general facts concerning the occurrence of this formation along his line of observation: The first disturbance, traveling westward from San Antonio to El Paso, is Sierra Diablo, or Limpia Range, near Fort Davids. The elevation at Leon Springs, the last point upon the horizontal, undisturbed Cretaceous strata before reaching this range, is some 2,200 feet above San Antonio,[6] giving an average rise of seven feet to the mile and a total elevation above the sea of 2,788 feet.

This range is characterized at nearly all the separate points noticed by Dr. Parry by the presence of igneous rocks accompanied by metamorphic rocks and strata of sedimentary character, which Professor Hall considered to be of the Carboniferous period. The dip varies, but is generally to the southwest. From this range westward to El Paso there are several other mountainous elevations and intervening plains, the former being of the character of the Limpia Range just mentioned and the latter consisting of alluvial deposits, the detritus from the surrounding mountains. At El Paso the character of the region again changes, a greater disturbance being noted. On the Mexican side the various formations, stratified and igneous, are blended and intermixed in great confusion, while on the American side the strata consist of stratified limestone dipping W.SW., in the face of which rest igneous outbursts associated with the disturbed Cretaceous beds.[7] This limestone was determined by Professor Hall to belong to the Carboniferous series, being a continuation of that above noted.

[1] Described in Report U. S. Geog. Surv. West of One Hundredth Meridian, under charge of Capt. G. M. Wheeler, Vol. III, Supplement, Geology.

[2] See Report U. S. and Mexican Boundary Survey, Vol. I, Part II.

[3] See Trans. Acad. Sci. St. Louis, Vols. I and II. Numerous papers by both Dr. G. G. and Dr. B. F. Shumard.

[4] Observations on the Carboniferous limestone of the Boundary Survey collections, and its relations with the Carboniferous limestones of the Mississippi Valley. By James Hall, in Report U. S. and Mex. Bound. Surv., Vol. I, Part II, p. 122.

[5] Trans. Acad. Sci. St. Louis.

[6] Report U. S. and Mexican Boundary Survey, Vol. I, Part II, p. 4.

[7] Ibid., p. 8.

Concerning its age, he said:[1]

The Carboniferous limestone so often mentioned in the preceding pages, and which has been usually referred to in published reports as "Carboniferous limestone" and as Lower Carboniferous limestone, is actually of the same age as the Coal Measures. * * * In all the collections which I have examined from Texas and New Mexico, and from points farther north in the same line, and particularly in the collections made by Captain Stansbury on his route from the Missouri to the Great Salt Lake and in that region, I have never observed fossils which are characteristic of the Lower Carboniferous limestone.[2]

Dr. G. G. Shumard's observations of these strata along the thirty-second parallel agree with those of Parry in general respects. Along this route he repeatedly found exposures of the Carboniferous strata, where he crossed the disturbed mountain chains of the Guadalupe, the Cornudos, the Sierra Alta, the Sierra Hueca, and the El Paso Mountains, respectively. In addition to the features noticed by Parry he observed the Lower Silurian (Cambrian?) underlying the Carboniferous to the north of El Paso and elsewhere.

He noted the following stratigraphic features of the region:

(1) It is underlaid by a granite bearing series (the Llano Group of Walcott?).

(2) The Carboniferous in some places rests conformably upon the Lower Silurian strata.

(3) The Cretaceous rests unconformably upon the Carboniferous.

(4) The Paleozoic strata of the region are greatly disturbed.

(5) The occurrence of characteristic fossils of the Coal Measures proves the age of these strata. Here, however, they were purely marine, the rocks being almost entirely of limestone and the fossils characteristic invertebrates similar to those of the Carboniferous of Missouri and Illinois.

Above these rested a later series, which he and his brother, Dr. Benj. F. Shumard, called the Permian,[3] containing fossils having many characteristics of Permian fossils and similar to the rocks of the same nature reported by Swallow and Horn and by Meek and Hayden in Kansas. Other species were said to be identical with characteristic Permian fossils of England and Russia and many were new to science.

Upon comparison with the Llano County strata, as noted by Roemer, Shumard, Walcott, and others, it will be seen that they have some common features. The distance between these two areas of disturbance, from Llano County to the intersection of the Guadalupe Mountains and the thirty-second parallel of latitude, is 300 miles, and the intervening surface is occupied by nearly horizontal undisturbed series of Mesozoic rocks, which at each place are unconformable with the

[1] Report U. S. and Mex. Bound. Survey, Vol. I, Part II, pp. 122, 123.

[2] This opinion of Professor Hall has been confirmed by observations of the extension of these strata farther north. See U. S. Geog. Surv. West of the One Hundredth Meridian, in charge of Capt. G. M. Wheeler, Vol. III, Supplement, Geology.

[3] Concerning these Permian strata I shall say more in the following pages.

Carboniferous, indicating beyond doubt that there was a period of great disturbance at the close of the Paleozoic.

It is very doubtful whether the Carboniferous strata of this region of the State are of economic value. Coal deposits have been discovered within the past few months very near the region visited by Dr. Shumard,[1] but their horizon is not announced.[2] Coals have also been reported north of El Paso, but their place in the geologic scale is Cretaceous, coal not now being considered as representing the Carboniferous age unless accompanied by stratigraphic or paleontologic proof.

General conclusions.—From the foregoing résumé of investigations of the Texas Carboniferous the following general facts are evident:

1. It occupies two widely separated areas the relation of which is unknown.

2. The first or central area consists of coal bearing strata and is allied by geographical continuity to the coals of Indian Territory, Arkansas, Missouri, Iowa, &c.

3. The second or trans-Pecos area belongs to the great western deposit of non coal bearing, marine Carboniferous of the West.

4. Both of these areas are greatly disturbed and the Cretaceous is deposited unconformably upon them.

5. Although one distinguished authority has announced the presence of sub-Carboniferous strata in Texas, their existence has not been demonstrated,[3] and both areas probably belong to the later Carboniferous, the trans-Pecos graduating into almost Permian facies.

THE SO-CALLED PERMIAN[4] OR PERMO-CARBONIFEROUS.

The term Permian has for many years been applied, with much indefiniteness, to certain Texas strata, and it is difficult to form from

[1] Sierra Blanca.

[2] It is now known that these coals are later Cretaceous.

[3] Prof. C. A. Ashburner announced that the limestone at the base of his section (see p. 59) was sub-Carboniferous. Prof. W. F. Cummins, of Dallas, Tex., first called my attention to the fact that Mr. Ashburner was probably mistaken. From personal observation I have also good reason for doubting its existence. Not a single sub-Carboniferous fossil has been found in Texas, and the limestone of the Central Coal Measures bears great lithologic and faunal resemblances to that of the non coal bearing western strata.

[4] The word Permian has been applied for many years to various strata in the great area between the western boundary of the exposures of the Missourian or fourth coal basin of the United States and the Sierras, especially in the States of Texas and Kansas, the Territories of New Mexico and Arizona, and in Indian Territory. Prof. J. S. Newberry, at the meeting of the International Geological Congress at Berlin (1885), asserted that he believed no Permian strata to exist in the United States. Whether the existence of Permian strata here can be proved or not I cannot say, but it has been clearly demonstrated that sedimentation was going on in this country synchronously with the deposition of the Permian of Europe. That this sedimentation was different from the European in lithologic and organic characters is true.

published writings even a general idea of what was intended by those who have most frequently used it.

It has been applied by different authors[1] to at least two entirely distinct geologic horizons occupying widely separated areas. Although one of these has been described with comparatively much more distinctness than the other, there is still much danger of confounding the two. No paleontologic or stratigraphic data have ever been produced showing any relation between them.

The trans-Pecos region of Shumard.—The first locality to which the term Permian was applied was the region west of the Pecos River, near the Rio Grande, occupied by the disturbed outliers of the Rocky Mountains, known as the Guadalupe Range or Ranges.

At a meeting of the St. Louis Academy of Science, held March 8, 1858, the following report was made:[2]

Dr. Benjamin F. Shumard stated that since he had examined Major Hawn's collection from the Permian rocks of Kansas he had studied a series of fossils from the White Limestone of the Guadalupe Mountains, New Mexico, which were obtained by his brother, Dr. G. G. Shumard, while acting in the capacity of geologist of the Government expedition, under Capt. John Pope, for obtaining water by means of artesian wells along the line of the thirty-second parallel, and that he had arrived at the conclusion that these also were of Permian age. This White Limestone, he remarked, contains a number of fossils that are identical with Permian species of England and Russia, while others are near analogues of characteristic Permian forms of those countries; several are also identical with Permian species, described by Professor Swallow,[3] from Kansas. The collection contains well marked examples of *Aulosteges*, a genus that has not been recognized in formations below the Permian. The species, however, were distinct from the English and Russian forms. There are specimens which agree perfectly with the descriptions and figures of *Camarophoria Schlotheimi*, *C. Geinitziana*, and *Productus Leplayi*, as given by Verneuil and King; also a *Productus* very analogous, if not identical, with *Productus Cancrini*, and a *Terebratula*, that agrees with *T. superstes* of Verneuil in every respect except that the dorsal valve of the American fossil is not quite so gibbous. There is also in the collection *Terebratula elongata*, *Terebratula (Spirifera) pectinifera*, *Spirifer cristata*, *Acanthocladia anceps*, *Synocladia*, and fragments of a *Monotis* which approaches nearest to *M. speluncaria*. Besides these, the collection embraces new species of *Productus*, *Spirifer*, *Chonetes*, *Corals*, *Trilobites*, and a slender *Fusulina* nearly two inches in length. Scarcely any of these fossils are positively identical with forms of our western [Missouri] Coal Measures.

In subsequent papers[4] Dr. B. F. Shumard described these forms more at length, and his brother, Dr. G. G. Shumard, contributed an article[5] giving a very succinct stratigraphic description of the region.

---

[1] B. F. and G. G. Shumard, 1860, and E. D. Cope, 1874.

[2] Trans. Acad. Sci. St. Louis, Vol. I, pp. 112–114, 1856–1860.

[3] Ibid., p. 111.

[4] "Notice of new fossils from the Permian strata of New Mexico and Texas, collected by Dr. George G. Shumard," &c., Trans. Acad. Sci. St. Louis, Vol. I, pp. 290-297; "Notice of fossils from the Permian strata of Texas and New Mexico," &c, ibid., pp. 387–415.

[5] Observations on the geological formations of the country between the Rio Pecos and the Rio Grande, in New Mexico, near the line of the thirty-second parallel, &c., ibid., pp. 273–289.

According to the latter the white, gray, and other colored limestones forming this series have a thickness of over a thousand feet, are greatly disturbed, and have a varying dip.

The extent of these exposures is probably identical with that of the trans-Pecos Carboniferous area already described, from which the rocks are stratigraphically inseparable. These occur entirely west of the Pecos River, so far as is now known, and between the Rio Grande and the thirty-second parallel. The only points where they have been positively noted are in the section of country from 30 miles west of the mouth of Delaware Creek to the mountains in the vicinity of El Paso, Tex., approximately following the thirty-second parallel. The United States and Mexican boundary survey party noted the occurrence of similar rocks along a section parallel to the foregoing, but from one to two hundred miles to the southward. In the report of the survey, however, which was printed a year or two before Dr. B. F. Shumard's application of the term Permian, these strata were termed Carboniferous. That they are identical there is little room to doubt.

Dr. Shumard pointed out many supposed resemblances to the so-called Permian of Kansas, and, if these are real, the two areas may be in some degree related.

Concerning the western extension of this region little is definitely known, but good authorities think there is reason to believe that it is more closely related to the Permo-Carboniferous, as described in Southern Utah and along the Grand Cañon of the Colorado in Arizona, than to the Coal Measures of the Mississippi Valley and the Appalachian region.

It would of course be impossible to make any definite statements about the equivalents of trans-Pecos Permian, but it is highly probable that future investigation may demonstrate more clearly the above mentioned resemblance.

There is no reason to doubt that these rocks are a continuation of the Carboniferous sedimentation, and the remarks of James D. Dana[1] concerning the Permian rocks of Kansas are equally applicable to them, to wit: They "are continuous with the Carboniferous without interruption or unconformability, and yet are referred to the Permian because they probably belong to the Permian in geologic time or at least its earlier portion." Whether these strata are of the Carboniferous or of the Permian, they present paleontologic and stratigraphic features of a purely transitional group. If it is granted, however, that these Texas and Kansas strata are the highest Paleozoic beds in this country and if it is shown that they contain a commingling of typical Carboniferous and Permian species, the term Permo-Carboniferous would be the most appropriate one that can be applied to them.

From all the literature we have upon the subject, it is evident that at the close of the time of the deposition of these trans-Pecos, Permo-

[1] Manual of Geology, p. 369.

Carboniferous strata a great elevation had been attained and that they must have remained a portion of a continental area for some time, when subsidence ensued and the Mesozoic sediments were next deposited unconformably upon them.

The Permian of Cope and his assistants.—The second area in Texas to which the term Permian has been applied (which it should be remembered may belong to an apparently different horizon from the trans-Pecos region just described) is situated along the western boundary of the northern portion of the central area of Carboniferous exposures continuing into Texas from Indian Territory approximately along the line of the one hundredth meridian and extending southward to the thirtieth parallel.

Although this formation has frequently been alluded to in the writings of Prof. E. D. Cope, Jacob Boll, and others, nothing has been printed concerning its stratigraphy or that of the surrounding country, except the fragmentary data which I have compiled and which I present in the following pages.

From Prof. W. F. Cummins,[1] of Dallas, Tex., I have learned that the term Permian was first applied to the region by Prof. William DeRyee, who occupied the office of State chemist during the war of the rebellion. Upon what geologic evidence Professor DeRyee called the region Permian I have been unable to ascertain. The printed statement from his pen is as follows:[2]

To the Directors of the Texas Copper Mining and Manufacturing Company:

GENTLEMEN: In accordance with instructions received at Weatherford on the 12th day of June [no year is given], I hereby transmit to you the following sketch of my researches in the Wichita copper region. The limited time which I was able to devote to it and the difficulties incident to an exploration of a comparatively uninhabited district will palliate its deficiency. After traversing the *Lias* and *Carboniferous* series northward of Weatherford, I was agreeably surprised by a grand panorama of the outcropping Permian formation. This system is extensively developed in Russia between the Ural Mountains and the river Volga, in the north of England, and in Germany, where it is mined for its treasures of copper, silver, nickel, and cobalt ores. It has not heretofore been known to exist in this State, or has been mistaken for the Triassic system, which is overlying the former to the southeast. Its hills, which have been traced through Archer and Wichita Counties, resemble in shape the copper bearing and gossan crested upheavals in Ducktown, Tenn., but they are of different age and composition. They are nearly barren and, towering above the most beautiful mesquite prairies fringed by the finely timbered tributaries of Red River, are exceedingly picturesque. The members of the Wichita system, as far as open to ocular inspection by outcrop or cross-cut, making allowances for climatic differences, correspond closely with the lower strata discovered at Perm and Mansfield, but its mineral resources are evidently more promising.

[1] This gentleman is the most thoroughly informed concerning the origin and history of the application of the term Permian, having been intimately connected with Messrs. Cope, DeRyee, and Boll, who applied it so frequently.

[2] Charter and by-laws of the Texas Copper Mining and Manufacturing Company. A history of the company. Letter from the Department of the Interior, by Joseph S. Wilson, Commissioner. Prof. Wm. DeRyee's and W. F. Cummins's Geological Reports. Dallas, Texas, 1883, p. 6.

Then follows a description of the mineral products of the formation, throwing no light on its age or stratigraphy.

The foregoing is the first and only description I have been able to find in print of the Permian of the Wichita region of Texas from the pen of the man who first applied that name to its geologic formation.

In the same pamphlet are geological reports from Prof. Jacob Boll and Prof. W. F. Cummins. The former says (p. 11) of the geologic age:

The company's land lies wholly within the transition period, especially within the lower Permian formation.

The latter says, however (pp. 8, 9):

I had visited frequently before this trip the immediate country in which these lands are situated and had already determined the geological period to which Archer County belongs. Under an engagement with Prof. E. D. Cope, of Philadelphia, Pa., I have been for the last two years collecting fossil vertebrates of the Permian period in Archer and adjoining counties. Archer County is almost entirely within the lower Permian period. The rocks and clays of the Permian thin out to the south, where there is a fine presentation of the rocks of the upper Coal Measures. The Permian strata in Texas lie conformably above the Carboniferous measures; in fact, the Permian and Carboniferous rocks constitute a continued series, so that it is impossible to determine just where one ends and the other begins; but I am certain the lands of the company are wholly within the Permian, for I have collected fossils on these lands that are undoubtedly of that period.

Prof. Jacob Boll made the first intelligible announcement of the Permian in Northwest Texas in a brief sketch in the American Naturalist for 1880.[1] He mentioned his explorations of the previous field season, which extended over the entire length of Little Wichita River and its confluents. As the result of this six months of exploration he announced that he had discovered many new "plants and animals, consisting of petrified ferns, fishes, and reptiles." These, he asserted, all belonged to the transitional period, and especially to the lower and upper Permian.

Such is the meager testimony upon which the existence of the Permian in Texas was originally announced. I have been able to gather from a few scattering newspaper articles a better understanding of the region thus termed Permian. These articles were written by Prof. W. F. Cummins, an intimate friend and companion of Professor Boll, who accompanied him upon his journeys of investigation. The substance of the observations given in these newspaper articles is here reproduced somewhat at length, as the original publications are now inaccessible to the public.

In an article published in The Galveston Daily News, of December 1, 1884, Professor Cummins describes a geologic expedition into the country which Professor Boll was exploring at the time of his death, in 1880, in the vicinity of the Double Mountain Fork of the Brazos River, The principal object of Professor Cummins's journey was to discover the

[1] Vol. XIV, p. 684, 1880.

extent of the Permian formation in that part of the State. He had previously traced the formation from the Wichita Mountains, near Fort Sill, Indian Territory, southward to the South Fork of the Brazos River. From the fact that Professor Cummins was such an intimate friend of Professor Boll, it is inferred that they had the same ideas concerning the use of the term Permian. According to Professor Cummins it would appear that—

(1) On the west side of the Carboniferous exposure, from Fort Griffin to the Clear Fork of the Brazos, there is a series of limestone hills similar to those in Baylor and Throckmorton Counties, which he considered Permian from their stratigraphic position above the Coal Measures, although unable to determine from the poorly preserved fossils and "the character of the rocks."

(2) At the base of these hills, on the east side of California Creek, are the "red marls of the Permian."

(3) Four miles farther west, still *at the base of the limestone hills*, is the vertebrate stratum,[1] which apparently has a wide extent and seldom exceeds two feet in thickness. Fossils are abundant in this stratum, "over fifty species heretofore unknown to science having been described from these beds" by Professor Cope.

(4) Twenty miles west of the above mentioned locality is Flat Top Mountain, presenting a vertical exposure of 250 feet. These rocks belong to the Permian, but are geographically too high for the vertebrate strata, only a few poorly preserved shells having been collected.[2]

(5) Twenty-five miles north of the above mountain is Kiowa Peak, situated at the junction of Croton Creek and the Brazos River. "A trip to the mountain disclosed the fact that it is of the Permian age. The whole mountain from top to bottom was a mass of saccharoidal gypsum." Fossil vertebrates were collected in the vicinity.

(6) At Double Mountain, to the south of the above mentioned locality, "the base of the mountain is gypsum, while at least two hundred feet above are Cretaceous, the Cretaceous shells being abundant and well preserved." Between the Permian and the Cretaceous beds is an unfossiliferous bed, 60 feet thick, similar to that "which immediately overlies the Carboniferous in Young and other counties, and which has hitherto been supposed to belong to that series of beds."

From the above data, together with my own observations in the region, the Permian of Messrs. Cope, Boll, and Cummins may be described as follows:

(1) A stratum of limestone, probably a part of that surmounting the true Carboniferous hills of Shackelford County, the Permian age of which is based upon its position, the fossils being pronounced indistinct by those who have seen them. This stratum of limestone is most prob-

[1] I have been informed that the vertebrate stratum is above the gypsum beds.

[2] No study has ever been made of the invertebrate fossils of the region.

ably that described by Ashburner[1] as outcropping a few miles from Cummins's locality and belonging under the Brazos coal bed, the superincumbent strata probably being washed away by erosion. It may possibly be the White Limestone of Shumard's trans-Pecos region.

(2) The red marls so characteristic of that region of Texas and described by many travelers as occupying the gypsum beds. According to Professor Cummins, these are at the base of the Carboniferous hills above mentioned, indicating non-conformability and later deposition.

(3) A vertebrate bearing stratum, the relation to the foregoing not being known, the fossils of which have been the basis of Professor Cope's term Permian.

(4) The well known gypsum strata of Texas, which have been so often mentioned in the literature of the State. These immediately underlie the typical Texas Cretaceous, a barren stratum of only a few feet intervening.

From the foregoing it will be seen that Professor Cope's Permian, as interpreted by Professor Cummins's observations, includes all the strata in Texas west of the central Carboniferous area from the late Carboniferous to the base of the Cretaceous, inclusive. It is doubtful whether this evidence, based upon a vertebrate bearing stratum and unaccompanied by any stratigraphic detail, is sufficient to justify the application of the term Permian to such an important and unexplored series of Mesozoic rocks.

The age of this series is still in the same condition of uncertainty as before Professor DeRyee applied a name to it. The rocks may be Carboniferous, Permian, Triassic, Jurassic, or Cretaceous, or all. It is certain that they are the representatives of the sedimentation of the entire Mesozoic age previous to the well authenticated Cretaceous. A little investigation would throw much light upon the subject.

Detailed comparison will now be considered unnecessary to show that there is no similarity between the two regions in Texas to which this term Permian has been applied. The Permian of Shumard, beyond the Pecos River, whether Permian or Carboniferous, occupies a clear stratigraphic position; it is well marked by a characteristic fauna; there is no doubt as to where it belongs in the geologic succession. On the other hand, the Permian of Cope has as yet no well defined stratigraphic relations; it is involved in ambiguous uncertainty and its fossils are of a vague and indefinite character. There are no stratigraphic, lithologic, or paleontologic points common to the two, and hence they have no established relationship whatever, the latter author having applied the name apparently without knowledge of its use by the other.

[1] "Brazos coal-field, Texas," Trans. Am. Inst. Mining Eng., Vol. IX, pp. 495–506, 1880–'81.

THE JURA-TRIAS OR GYPSUM STRATA.

The few geologic observers who have traveled in Texas west of the ninety-ninth meridian, south of the North Fork of the Canadian, have all commented upon the occurrence of immense gypsum deposits in that region, but so far as I am aware no one has endeavored to offer any hypothesis as to their formation or to interpret their accompanying phenomena. Captain Marcy was the first observer to give this formation extensive notice, but he throws little light on its stratigraphic relations. He records numerous localities of occurrence, however, which are of value. He describes the strata as snow white gypsum, from fifteen to twenty feet thick, resting horizontally upon substrata of red clay and sometimes accompanied by red sandstone. Mr. Jules Marcou, who observed the same formation a few miles north of Captain Marcy's localities, in his notes conveyed the idea that these beds were white and rose colored gypsums; the beds were from one to twenty feet thick, a thin, argillaceous dolomite being found below them. Captain Pope also noted the occurrence of the same beds several hundred miles to the southwest, on Delaware Creek, where Dr. G. G. Shumard, who accompanied both him and Captain Marcy as geologist, affirmed his identification. At various other points west of the central Carboniferous exposure, between Red River and the mountains west of the Pecôs, these gypsum strata have been noted and many sections given. I have observed them at several of the localities mentioned, and in Jones, Haskell, Mitchell, and other counties. At every point these gypsum strata are of the same character, consisting of white or pink deposits of saccharoidal, hydrous calcium sulphate. Sometimes they are accompanied by deposits of magnesium and other sulphates.

That these gypsum beds do exist; that they extend over a large area of country; that they do not consist of fragmentary crystals or impregnations, but are extensive, massive bedded strata, presenting a similarity of structure indicative of identical deposition, is now evident.

What bearing or relation they have to the geologic structure and history of Texas, is a most pertinent question. So far as I am aware no study has been made in this direction. Previous to 1860, when these beds were attracting the greatest attention, the formation of gypsum was little understood, and there has been no interpretation of the bearings of this region upon our American geology. The simple laws of chemical and physical precipitation of limestones, gypsums, and dolomites have but recently become aids to the stratigraphist in his studies.

The fact that the typical strata of the peculiar Cretaceous rocks of Texas have been observed by Professor Cummins and others resting immediately upon these gypsum beds is evidence that their age is pre-Cretaceous, and not the age of the Dakota group, as has recently been averred by students of the gypsum strata of Kansas. I also have reason to believe that some of the numerous "red beds" of the gypsum region are Carboniferous, but that the age of the gypsum beds themselves is still unknown, except that they are intermediate between the Carboniferous and the Cretaceous, including what has been termed the Permian and the Jura-Trias. The intimate stratigraphy of these beds is not known, but it is probable that they are the eastern exposure of the immense deposits of the "red beds" observed throughout the Southwest, especially in New Mexico, Utah, and Arizona.

THE SO-CALLED JURASSIC ROCKS OF TEXAS.

I have already shown (page 54) that Mr. Jules Marcou referred certain of the Mesozoic rocks of Texas to the Jurassic. These rocks were along the breaks of the Llano Estacado and along the Canadian River near the boundary of New Mexico. I have also alluded to the fact that Mr. Marcou's opinions were attacked by nearly all of the leading geologists of the day,[1] none of whom visited the region, except perhaps Dr. Newberry. It was a warfare of theoretical discussion, for very little was known of the region. Mr. Marcou held to his point,[2] and has not yet conceded that these strata are Cretaceous, as his opponents unanimously maintained. It is highly probable that the fossils *Gryphæa dilatata* and *Ostrea Marshii*, upon the occurrence of which Marcou held his position, are the same species that Dr. Shumard afterwards described as *Gryphæa Pitcheri* and *Ostrea belliplicata*, and now known to occur in the well defined Cretaceous of Central Texas; but it is certain that Marcou's allegations that these fossils are Jurassic were founded upon as logical grounds as those of his opponents, who, at a distance, made them equal to the Upper Chalk. It is probable that they are the continuation of Jurassic forms into the Lower Cretaceous, which Marcou called elsewhere "Neocomian;" and from later and more definite information it is very probable that Marcou's Jurassic is basal (not Upper) Cretaceous.

Another writer, Mr. N. A. Taylor, has been outspoken in referring the Cretaceous strata of Texas to the Jurassic. He thus expresses himself:[3]

> The conformation of this great region seems to show unmistakably that it was once an inland sea, whose southern shore was probably at first along the Azoic hills below the San Saba, contracting gradually to the great backbone between [Fort] McKavett and Kickapoo Springs, whose western shore extended at least thus far, and whose northern shore may have reached the Red River. Its eastern shore probably crossed the Colorado above the mouth of the Concho, extending northward to the limit of Texas and perhaps beyond. This immense basin slopes inward from

[1] See "Criticisms on Marcou's work by American geologists," Am. Jour. Sci., 2d ser., XXVI, p. 323; 2d ser., Vol. XXVII, pp. 34, 134; 2d ser., Vol. XXVIII, pp. 153, 256, and 298; Report of U. S. Geological Survey, Vol. IX; Report of U. S. and Mexican Boundary Survey, Vol. I, Part II; Pacific Railway Reports, Vols. II and III, quarto editions.

[2] See Geology of North America, by Jules Marcou, Zurich, 1858, for gist of Mr. Marcou's defense.

[3] See The Coming Empire, or Two Thousand Miles in Texas on Horseback, by H. F. McDaniels and N. A. Taylor, pp. 314, 315, 1878.

every direction, but its deepest parts are probably along the valleys of the Concho, not far from its southern border. The altitude of Fort Concho is only one thousand nine hundred feet above the level of the sea, while that of the great ridge below Kickapoo Springs and this on which I stand must be quite a thousand feet higher. This sea in drying up left enormous deposits of gypsum, great beds and areas of salt and other alkalies, with which all the streams that flow through its ancient bed are more or less impregnated. This sea, as I believe, existed during the Jurassic age. The geologists who have written of this region, from observations at telescopic distance or no observations at all, have all assigned it to the Cretaceous; but my judgment is that there is little or no Cretaceous in it. I have seen no fossils to confirm this judgment; but this basin in general outline is totally unlike the Cretaceous as developed in other portions of Texas or elsewhere. Nor has that formation in any part of the globe, if this be Cretaceous, developed such enormous deposits of gypsum and salt. If, then, it is Cretaceous, it is anomalous and without precedent.

The region he alludes to is the central or denuded area. He says:

This portion of Texas has never been geologically examined, except in a most cursory way, and it is not always easy to distinguish Jurassic from Cretaceous fossils. The late State geologist, Professor Buckley, rode over it in an ambulance, not deviating from the El Paso stage road.

Mr. Taylor has simply taken the work of subaërial erosion to be that of a lacustrine shore line, and his Jurassic sea is the denuded area of all the formations from the Carboniferous into the Cretaceous.

Although no one could say positively that there are no strata of the Jurassic age in Texas (for the problematic gypsum bearing red beds may be of that age), it is perfectly safe to say that none have as yet been demonstrated to exist.

THE CRETACEOUS.

The Cretaceous strata of Texas form by far the most extensive and important geologic deposit of that State. Fortunately for science the earliest writings on this particular formation were very explicit. Dr. Ferdinand Roemer's Kreidebildungen von Texas and his other writings on the subject, however erroneous they may be in their deductions, are exceedingly complete and clear, so that in their perusal there can be but little doubt as to the exact opinions he entertained. He studied the Cretaceous rocks of the State from the marine Tertiary on the east to the Paleozoic rocks in the Llano County region, embracing a cross section of the entire thickness of the series. This was from Seguin to the old Spanish fort on the San Sába. He also collected all possible legendary evidence and platted upon a map his ideas of the distribution of the Cretaceous strata in Texas. His descriptions and figures of the fossils of this formation remain to this day the most accurate and perfect of any paleontologic literature of the country. The principal points he developed concerning this formation were as follows:

(1) He delineated its eastern border as extending from Presidio del Rio Grande northeastward 440 miles to the Red River, enumerating many intermediate points. This line is generally accepted to-day.

(2) He explained the peculiar lithologic characteristics—a white chalky rock, with the appearance and consistency of the German Plä-

nerkalk, containing calcite crystals and flint nodules, a chalk marl, and a harder yellow limestone.

(3) He gave the first exposition of its organic remains and asserted their great similarity to the fauna of the Upper Cretaceous of Southern Europe.

(4) He gave the fauna of the various strata and of different localities, describing 118 species, 58 of which were new to science.

(5) He noted the escarpment line, running from the neighborhood of San Antonio northward, via New Braunfels and Austin, to an indeterminate point north of the latter city. He found the Cretaceous formation to extend in a comparatively narrow strip along the base of this escarpment, as well as far to the west along the surface of the tableland, of which it was the boundary.

He found well differentiated faunas in each of these topographic areas, and accordingly divided the formation in two great subdivisions,[1] to wit: Die Kreidebildungen am Fusse des Hochlandes (the Cretaceous formation at the foot of the highlands) and Die Kreidebildungen des Hochlandes (the Cretaceous of the highlands). He discussed the last named formation as the Cretaceous as he found it near Fredericksburg[2] and the Cretaceous eight miles west of New Braunfels.[3] Of these divisions and subdivisions he considered the Fredericksburg, or most western outcrop, the newest, and the Cretaceous at the foot of the highlands the oldest, and expressed the opinion that there could be no doubt that the latter extended under the highlands, instead of resting unconformably upon it, which recent investigations have shown to be the case.

---

[1] Dr. Roemer made no tabulated section of the Cretaceous of Texas, but from many statements in the text of his works it is evident that he had the following opinions of the subdivisions:

There are three general divisions of the Cretaceous in Texas, to-wit: The Cretaceous at the foot of the highlands; the Cretaceous of the highlands; the Cretaceous of the hills near Fredericksburg.

On page 17 of Kreidebildungen he says: "It is known that the hills in the country to the north of Fredericksburg, on the Pedernales River, are the latest of all the Cretaceous of the highlands of Texas." On page 18 of the same work, he says: "After these observations it cannot be longer doubted that the Fredericksburg strata belong to the youngest of the three accepted divisions of the Cretaceous period."

Concerning the relation of the Cretaceous of the highlands to that at their foot, he says (Texas, p. 379): "Before we can enter upon a discussion of the general significance of the Cretaceous strata in Texas we must endeavor to investigate how the Cretaceous, which caps the high table-lands of Texas, consisting of a series of silicious, chalky strata, are related to the earlier observed formation at the ford of the Guadalupe, near New Braunfels, and at other points along the foot of the highlands, consisting of less firm white limestone and marls. The undoubted succession of these strata cannot be seen plainly at New Braunfels.

"But, since the firmer strata of the highlands plainly occupy a much higher bluff, it is not to be doubted that here at New Braunfels the loose white chalk and chalk marls are the lowest and the firmer limestones of the highlands the highest."

[2] Comanche Peak group of Shumard.

[3] Washita Limestone of Shumard.

He intimated the westward extension to the Rocky Mountains of the Cretaceous formation, and showed that it differed materially in its organic and lithologic characters from what is now known as Meek and Hayden's section in the Northwestern Territories and that it bore slight resemblance to the Alabama section, based upon the occurrence of Hippurites.[1] He also asserted, upon the occurrence of identical organic remains, that this formation was equivalent to the Upper Chalk and displayed by both its paleontologic and its lithologic characters a resemblance to the Upper Cretaceous of Southern Europe in the countries bordering on the Mediterranean.

From the above facts, together with similar observations upon the relation of the Cretaceous of New Jersey with that of Northern Europe, he derived the following important conclusions concerning the Cretaceous of Texas:[2]

(1) The rocks of the Cretaceous period in Texas, which are generally of a chalky character, have an extensive distribution, reaching from the Red River to the Rio Grande, comprising the greatest part of the highlands (central region) and the southern border, even extending into the undulating region (black prairie).

(2) The rocks vary greatly in character, those of the undulating region (black prairie region) consisting of white, chalky limestones of little firmness, and those of the highlands (central region) of a great system of strata consisting in part of very firm limestone layers, with inclosures of flint nodules and intervening layers of marls.

(3) The Cretaceous formations of Texas collectively belong to the Upper Chalk (i. e., the chalk above the Gault), and so much so that they may be referred to the horizons of the white chalk (Étage Sénonien d'Orbigny) and the upper part of the chloritic chalk (Étage Turonien d'Orbigny) of Europe.

(4) The rocks of the Cretaceous formation in Texas, particularly those of the highlands (central region), upon comparison show a decided analogy with the Upper Cretaceous formations of Southern Europe, especially along the Mediterranean, which analogy is especially seen in the strong representation of the fossil family of Rudistes.

(5) The same physical differences in the natural conditions of the oceanic regions of the north of England and Northern Germany, on the one hand, and those of the Mediterranean on the other, that existed at the close of the Cretaceous age and that caused the variance in faunas and lithologic characters of the synchronous deposits in these two regions, existed at the same time and do still exist in the seas of North America. From these facts it is evident that the Cretaceous of New Jersey then bore the same relations to that of Texas[3] as did that of the north of Europe to that of the Mediterranean, and that the same northerly deflection of the isothermal lines from the eastern coast of North America to the western coast of Europe, was evident at so early a time in the earth's history as the Cretaceous.

The next observation of the Cretaceous strata of Texas was made by Dr. G. G. Shumard along the northern border of the State. He included the strata which his brother, Dr. B. F. Shumard, afterwards incorporated in his section under the name of Washita Limestone. These he traced from Fort Washita (a few miles north of the present

[1] Radiolites, as corrected in Kreidebildungen.

[2] Kreidebildungen, pp. 25, 26.

[3] The next to the latest of the European Cretaceous.

city of Denison) to east of Fort Belknap, in Young County. A comparison of his descriptions with those of Roemer shows that the Cretaceous of this northern region of Texas has many paleontologic similarities with that described by Roemer from an Indian camp on the Guadalupe, eight miles west of New Braunfels, but that their lithologic features vary greatly.

Dr. G. G. Shumard said of these strata:[1]

From this point [Fort Washita], the Cretaceous rocks were found to extend uninterruptedly until we reached the southwestern boundary of the cross timbers in Texas. From the best information I was able to procure it constitutes the prevailing formation from Fort Washita in the direction of Fort Towson for upwards of a hundred miles with an average breadth of fifty miles. It forms part of that extensive belt of Cretaceous strata that extends from Georgia to Texas, and which, from the character of its fossil fauna, is now regarded as the equivalent of the Upper Chalk of England, and with that division of the Cretaceous group to which d'Orbigny gives the name of l'Étage Sénonien. Wherever sections of the strata were to be seen, they presented the following characters: Grayish yellow sandstones, with intercalations of blue, yellow, and ash colored clays and beds of white and bluish white limestone. The limestone reposes on the clays and sandstones. At some points it attains the thickness of a hundred feet, while at others it is quite thin and sometimes even entirely wanting. It is usually soft and friable and liable to disintegrate rapidly when exposed to the action of the weather. These Cretaceous rocks are often full of fossils. At Fort Washita the layers are crowded with *Ananchytes*, *Hemiaster*, *Nucleolites*, *Ammonites*, *Ostrea*, *Pecten*, &c., descriptions and figures of which will be found in Dr. B. F. Shumard's reports on the paleontology of the expedition. We saw here some specimens of *Ammonites* several feet in diameter and weighing between four and five hundred pounds.

Mr. Jules Marcou published a more accurate description of the Fort Washita strata and fauna a year after Dr. G. G. Shumard. He showed that in that region they were greatly denuded and covered to the east by higher strata like those of Arkansas and Mississippi. He asserted that the true age of the Fort Washita strata was Neocomian.[2]

The first results of the expedition were published by Mr. Marcou, prefaced with the statement that he had as yet neither the specimens which he had collected nor a good map of the country passed through, and since the time was very short in which he could make the required report he begged that its brevity and incompleteness be excused. In this paper he announced the existence of various formations which he more or less correlated with European strata. He described the red beds of the western portion of the Indian Territory as the Trias and discussed its divisions. The most important announcement, so far as concerns the geology of the Texas region, was as follows:[3]

I have mentioned two points between Topofki Creek and Anton Chico, where the Triassic rocks are covered by more modern formations. The first of these points is

[1] Expl. Red River of La., 1852, by R. B. Marcy and Geo. B. McClellan, p. 158.

[2] This is the only recorded reference of Texas Cretaceous strata to a position below the Gault.

[3] Geology of North America, by Jules Marcou, p. 17, 1858. The wording varies from that used in the résumé printed as a part of House Doc. 129, 1854, Lieutenant Whipple's report, p. 40, and makes locations more explicit.

upon one of the tributaries of the False Washita River, Comet Creek (latitude 35° 32′ 21″, longitude 99° 14′ 40″), near our camp, No 31, where, upon the heights, are found the remains of beds of a limestone filled with shells which I connect with the Neocomian of Europe, or, in other words, with the Lower Division of the Cretaceous rocks. This limestone is only 5 feet thick; it is of a whitish gray color, containing an immense quantity of *Ostracea*, which I consider as identical with the *Exogyra* (*Gryphæa*) *Pitcheri* Mort. * * * having the closest analogy with the *Exogyra Couloni* of the Neocomian of the environs of Neufchâtel (Switzerland). As it is the first time the Neocomian has been recognized in America, where, until now, only the Greensand and Chalk Marl or Lower Chalk have been found, I will add that these strata are much more developed at Fort Washita, where Dr. G. G. Shumard has made a collection of fossils such as *Pecten quadricostatus*, *Gryphæa Pitcheri*, *Cardium multistriatum*, *Ammonites acuto-carinatus*, *Holaster simplex*, all fossils or genera characteristic of the Neocomian of Europe. Further, at Fort Washita, the Neocomian is covered by the Greensand, containing very fine *Hemiaster*, large *Ammonites flacidicosta*, *Gryphæa sinuata* var. *Americana*, *Exogyra Texana*, &c.

This Neocomian has nearly been destroyed and carried away by denudations, for it is only found on the summits of the hills, where it appears like the ruins of ancient buildings; it occupies actually only a width of three or four miles. Probably at the time of the deposit it covered more space, but as at Fort Washita, where it has been very little denuded, it is only twenty-five or thirty miles wide. This shows it to have been but a narrow band in the immense basin of the prairies.[1]

The other reference of Mr. Marcou relating particularly to the geology of the State of Texas, although made, like the foregoing remark, upon strata continued beyond its border, was to the effect that certain other rocks on the Llano Estacado were Jurassic, as follows:

These rocks belong to the Jurassic or Oölitic epoch. Fossils are very rare in the sandstone and limestone; but the beds of blue clay which are found in the middle of this formation contain in abundance a *Gryphæa* which has the greatest analogy with the *Gryphæa dilatata* of the Oxford Clay of England and France, and which I call provisionally *Gryphæa dilatata* var. *Tucumcarii* * * * and a very large *Ostrea*, having a resemblance to the *Ostrea Marshii* * * * of the Inferior Oölite of Europe. * * * This American Jurassic presents, at least thus far, one point of considerable difference from the Jurassic of Europe and Asia, where such large quantities of *Cephalopoda* are found, such as *Ammonites* and *Belemnites*, while here the *Ammonites* are only found in the Greensand and the *Belemnites* in the Marly Chalk; and even there these fossils are never so abundant as in the corresponding strata of Europe.

In another preliminary paper, based upon specimens collected by Captain Pope's expedition, which he did not accompany, Mr. Marcou speaks as follows of the Cretaceous rocks in the vicinity of Preston, Tex., near the present site of Denison:[2]

Preston and its environs are formed of the Cretaceous rocks that extend along the Red River and the False Washita as far as the Canadian River. These rocks form also

[1] Field observations by the writer, made and published since the manuscript of this bulletin was sent to press, show that this small and hitherto unappreciated description of Mr. Marcou is really the most accurate that has ever been written on the Cretaceous formations of the Indian Territory, and that it is equally applicable to those of Texas, of which they are the continuation.

[2] In House Doc. 129, 1854. Rep. of Exploration of a Route for the Pacific Railroad near the Thirty-second Parallel of Latitude from the Red River to the Rio Grande. By Bvt. Capt. John Pope, Chap. XIII, Geol. Notes of a Survey of the country comprised between Preston, Red River, and El Paso, Rio Grande del Norte, p. 25.

the beds of the several tributaries of the Trinity River, especially of the Elm Fork of the Trinity, where your survey has found this formation very well developed, with numerous fossils. The Cretaceous consists at the base of yellowish gray limestones filled with broken oysters, of which the most common species is the *Gryphæa Pitcheri*; then pale grayish blue clays are superposed, containing numerous fossils, such as *Exogyra Texana, Ostrea carinata, Pecten quinquecostatus, Toxaster Texanus*, &c. Upon these clays are sandy limestones, grayish white, containing large *Ammonites* and *Baculites*; the most common are *Baculites asper* and several other new species that you have collected and which I will describe in the final report. The lower part, formed of limestone with *Gryphæa Pitcheri* and blue clay with *Toxaster Texanus*, corresponds with what is called by geologists the Neocomian formation, while the upper portion, containing *Ammonites* and *Baculites*, corresponds to the formation designated as Greensand and Marly Chalk.

The next cross section of the Cretaceous strata was made along the Rio Grande, by Arthur Schott,[1] of the United States and Mexican boundary commission. This he describes as "a Cretaceous basin, which consists chiefly of strata of greensand, which extends from Las Moras to the vicinity of Reynosa, and forms a belt of 380 to 400 miles in width" (p. 34) in Texas and Mexico. In this basin he notes various lithologic characters and some slight local disturbances. In this region, "from Las Moras to the vicinity of Arroyo Sombreretillo, which is about ten miles above Laredo, lignite coal occurs frequently" (p. 35). "Prints and even remains of plants preserved in these coals indicate vegetable forms of the higher orders, as Gramineæ, and even dicotyledonous trees, such as willow and ash" (p. 35). He also notes the extension of these coals into the Santa Rosa mountainous regions of Mexico, where the strata are nearly vertical. The fossils, plants, and mollusks from these localities bear a close affinity to the coal bearing beds of the late Cretaceous of the Northwestern Territories, but their relation to that region as well as to the Cretaceous of the west of Texas is still problematic.

Dr. Benjamin F. Shumard was the next geologist to study the Cretaceous strata in the field. He had the advantage of previous observations as well as of residence in the State for a few years as State geologist (1858–1861). His writings give evidence of much labor, but, like Dr. Roemer's, they are deficient in stratigraphy and are mostly of a paleontologic character. His section of the Cretaceous strata of Texas has been accepted to the present time by most writers. I quote the section with his immediate comments upon it:[2]

The order of succession and thickness of the different members of the Cretaceous system, so far as observed in Texas, are expressed by the following section, which is believed to be in the main correct, although it is not improbable that further researches may render some slight modifications necessary.

[1] Substance of the Sketch of the Geology of the Lower Rio Bravo del Norte, by Arthur Schott, asst. surveyor U. S. B. C., &c. Report of U. S. and Mex. Boundary Surv. Vol. I, Part II, pp. 28–48, 1851.

[2] Trans. Acad. Sci. Saint Louis, Vol. I. pp. 582–589, 1856–1860.

	Subdivisions.	Feet.	Characteristic fossils.	Eq. Nebraska section.	Eq. Alabama section.	Eq. Pyramid Mt. sec.
Upper Cretaceous or Calcareous division.	Caprina Limestone......	60				
	Comanche Peak group..	300 to 400	Exogyra Texana, Gryphæa Pitcheri, Janira occidentalis, Cardium multistriatum, Lima Wacoensis, Ammonites Pedernalis, Natica Pedernalis, Heteraster Texanus, Holectypus planatus, Cyphosoma Texana, and Diadema Texana.	Wanting.	Wanting.	Wanting.
	Austin Limestone ...... Fish bed...............	100 to 120	Gryphæa vesicularis, Exogyra costata, Radiolites Austinensis, Nautilus Dekayi, Baculites anceps. Fish remains — Mosasaurus,	Nos. 4 & 5 (?)	A B C	
	Indurated Blue Marl...	60	Exogyra arietina, Dentalina.	No. 3.	Wanting.	E F G
	Washita Limestone.....	100 to 120	Gryphæa Pitcheri var. Tucumcarii, Ostrea subovata (O. Marshii, Marc.), O. carinata, Inoceramus problematicus, Hamites Fremonti.			
	Blue Marl...............	50	Inoceramus problematicus, Ostrea, &c.	No. 2.		
	Caprotina Limestone...	55	Orbitolina Texana. Caprotina Texana. Natica acutispira.			
Lower Cretaceous.	Arenaceous group...... Fish bed...............	80	Ostrea bellarugosa. Cyprina (?). Fish remains.	No. 1.	E	B C D
	Marly Clay or Red River group.	150	Ammonites Swallovii, A. Meekianus, Ancyloceras annulatus, Scaphites vermiculus, Baculites gracilis, Gervilia gregaria, Inoceramus capulus, fossil wood.			A

I. UPPER CRETACEOUS OR CALCAREOUS DIVISION.

This division, in the eastern or settled portion of the State, attains a thickness of from 800 to 1,000 feet, but in its western extension reaches a much greater development. It presents the following subdivisions from above downwards: *Caprina Limestone, Comanche Peak group, Austin Limestone, Exogyra arietina marls, Washita Limestone, Inoceramus problematicus beds*, and *Caprotina Limestone.*

Caprina limestone.—This is the uppermost recognized member of the series, and, although of no great thickness, has a somewhat extended geographical range. It is a yellowish white limestone, sometimes of a finely granular texture and sometimes made up of rather coarse, subcrystalline grains, cemented with a chalky paste. It generally occurs in thick, massive beds, and is capable of withstanding the action of the weather to a greater extent than most of the members of the Cretaceous system. This formation is usually found capping the highest elevations, and its presence may be nearly always recognized, even at a distance, by the peculiar flat-topped and castellated appearance it imparts to the hills [buttes]. According to Dr. Riddell, it is finely displayed along the bluffs of Brazos River, in Bosque, McLennan, and Hill Counties; also along the Leon and Bosque Rivers. The summits of the remarkable elevation known as Comanche Peak, in Johnson County, and that of Shovel Mountain, in Burnet County, consist of this rock.

The fossils are chiefly *Caprina*, *Cytherea*, and *Ammonites* of undetermined species.

Comanche Peak group.—The Comanche Peak group, which next succeeds in descending order, is an important member of the series, and presents a greater development, both horizontally and vertically, than either of the others. It is made up of soft yellowish and whitish chalky limestone and buff and cream colored limestones of greater or less compactness. * * *

The best exhibitions of this formation that we have seen are at Comanche Peak, Shovel Mountain, and at Mount Bonnell, near Austin.

Fossils: This group is remarkably rich in organic remains, a large portion of them, however, occurring usually as casts. The species most frequently observed are *Exogyra Texana, Gryphæa Pitcheri, Janira occidentalis, Cardium multistriatum, C. Texanum, C. Coloradoense, Pholadomya Sancti-Sabæ, Lima Wacoensis, Arcopagia Texana, Trigonia crenulata, Astarte lineolata, Cardita erminula, Corbula occidentalis, Modiola contricostellata, Leda, Thracia, Ammonites acuticarinatus, A. Pedernalis, Scolaria Texana, Phasianella tumida, Rostellaria* (*Eulima* Sh.) *subfusiformis, Natica Pedernalis, Nerinea acus, Avellana Texana, Turritella seriatim-granulata, Cerithium Bosquense, Pleurotomaria* (undet. sp.), *Solarium* (undet. sp.), *Heteraster* (*Toxaster* Roe.) *Texanus, Holectypus planatus, Cyphosoma Texanum,* and *Diadema Texanum.*

It is quite probable that this and the preceding subdivision of our Cretaceous system are not represented in Nebraska. We have collected more than fifty species of fossils from these beds and not a single one has been found identical with any of the numerous Nebraska forms that have been described by Messrs. Meek, Hayden, Hall, the writer, and others. Neither have we seen any paleontological evidence that the beds under notice are parallel with any of the members of the New Jersey and Alabama series, though it is not improbable that a closer study of the Cretaceous rocks in Alabama will show them to exist there.

Austin Limestone.—This subdivision consists of cream colored and bluish earthy limestone, and resembles in lithological features portions of the preceding group, but contains quite a different assemblage of organic remains. Some of the beds are soft and crumble readily upon exposure, while others are moderately hard and furnish a handsome building rock, which may be cut into almost any required shape with a common handsaw. The State house and several of the public buildings at Austin are constructed of this stone. This formation occurs at Austin and near San Antonio and New Braunfels. Dr. Riddell also recognized it in McLennan and Bosque Counties and Dr. G. G. Shumard in Grayson County. The greatest thickness observed is in the vicinity of Austin, where the beds are exposed to the height of about one hundred feet.

Organic remains: The most characteristic [fossils] are *Inoceramus biformis, Gryphæa vesicularis, Exogyra costata, Ostrea anomiæformis, Arca vulgaris, Radiolites Austinensis, Nautilus DeKayi* (?), *Baculites anceps, Helicoceras, Ammonites, Cassidulus æquoreus, Hemiaster parastatus,* and scales and teeth of fishes.

At the base we have shaly layers of dark bluish gray calcareous sandstone, containing numerous fish scales, teeth of *Corax heterodon, Lamna Texana,* and remains of *Mosasaurus.*

This assemblage of fossils establishes pretty clearly that the Austin Limestone represents divisions A, B, and C of the Alabama section, as determined by Professor Winchell, which are regarded by Messrs. Meek and Hayden and Professor Hall as on a parallel with Nos. IV and V of the Nebraska section.

Exogyra arietina marl.—This is an indurated blue and yellow marl, with occasional bands of gray limestone and thin seams of selenite interstratified. It contains iron pyrites in the form of small spherical masses and the fossils are also frequently studded with brilliant crystals of this substance. It is well exposed towards the base of Mount Bonnell, near Austin, where it presents a thickness of about sixty feet. It may also be seen to advantage near New Braunfels, in Comal County, at various points in Bell County, and Dr. G. G. Shumard found it resting upon the limestone of Fort Washita, in Arkansas.

Fossils: *Exogyra arietina, Gryphæa Pitcheri, Janira Texana,* and a small undescribed species of *Dentalina.* On Shoal Creek, near Austin, *Exogyra arietina* occur in the greatest profusion, the surface of the ground being sometimes literally covered with them.

Washita Limestone.—This important member of our Cretaceous system is made up of a nearly white, yellow, gray, and blue limestone, some of the layers being moderately hard, while others disintegrate rapidly from exposure. This formation is exhibited at many localities in the State. Good exposures occur near Austin and in Grayson, Fannin, and Red River Counties. According to Dr. G. G. Shumard, it is finely developed at Fort Washita. * * *

Blue marl.—This member was examined in Grayson County by Dr. G. G. Shumard, who describes it as an indurated, arenaceous marl of a schistose structure, with small nodules of iron pyrites and irregular masses of lignite disseminated through it. It has not been recognized south of Grayson County.

The fossils are *Inoceramus problematicus, Ostrea,* and *Plicatula,* of undetermined species. It also abounds in fish remains, the scales and teeth of which are sometimes elegantly preserved.

This subdivision should, perhaps, be grouped with the preceding. It corresponds with No. 2 of the Nebraska section.

Caprotina Limestone.—The Caprotina Limestone, which follows in descending order, forms the base of the Upper Cretaceous and is composed of light gray and yellowish gray earthy limestone, with intercalated bands of yellow marl and sometimes flint. It is exposed at the base of the hills near Comanche Peak and is seen underlying the Washita Limestone near the Colorado, at the foot of Mount Bonnell.

Fossils: The lower portion abounds in *Caprotina Texana* and the upper portion contains *Orbitolina Texana, Panopæa Newberryi, Cardium Brazoense, Arca Proutana, Cytherea, Cyprina, Natica acutispira, Phasianella perovata,* and *Cerithium,* and *Nerinea,* of undetermined species.

II. LOWER CRETACEOUS.

For a knowledge of this division of our Cretaceous system I am indebted to Dr. G. G. Shumard, who has had excellent opportunities for examining it. He describes it as being composed of sandstones and gypseous and marly clays, the latter containing numerous septaria, filled with fossils. It is separable into two groups, namely, Arenaceous and Marly Clay or Red River group.

Arenaceous group.[1]—This member consists of light yellow and blue sandstone and beds of sandy clay, with crystals of selenite and some lignite. Its characters may be understood from the following section, taken by Dr. G. G. Shumard on Post Oak Creek, in Grayson County:

No. 1.	Soft, fine grained, yellow sandstone	10 feet.
2.	Hard, fine grained, blue sandstone, becoming yellow upon exposure, and sometimes passing into gritstone and fine conglomerate	5 feet.
3.	Yellow sandstone, same as No. 1	10 feet.
4.	Indurated, blue, slaty clay, with crystals of selenite	20 feet.
5.	Thinly laminated layers, same as No. 2	3 feet.

[1] Dakota Sandstone. See Trans. Acad. Sci. St. Louis, Vol. II, p. 140, quoted, p. 176.

Fossils: The upper part is characterized by *Ostrea bellarugosa* [*O. belliplicata ?*], *Ostrea congesta*, *Lucina*, *Plicatula*, a small species of *Cyprina (?)*, fossil wood, and occasionally obscure impressions of plants. The *Ostrea* occurs in distinct bands and is extremely abundant. The lower beds have yielded an undescribed species of *Lingula* and abound in fish remains which Dr. Leidy refers to the following species: *Ptychodus mammilaris*, *Lamna compressa*, *L. Texana*, *Galeocerdo pristodontus*, and *Carcharodon*. * * *

With regard to the Nebraska equivalent of our Arenaceous group, I think there can scarcely be a doubt that it represents No. 1 (perhaps the upper part) of the section of Messrs. Hall, Meek, and Hayden. * * *

Marly Clay or Red River group.—This member immediately underlies the fish bed of the Arenaceous group and is described by Dr. G. G. Shumard as "a blue, marly clay occasionally variegated with red and brown, and with thin bands of sandstone interstratified. The clay contains crystals of selenite, flattened nodules of compact brown and blue limestone, and septaria of compact, blue limestone, reticulated with brown, yellow, and purple spar. The nodules occur in the upper, and the septaria towards the base of the formation. The best exposures of the group are in Grayson, on Post Oak, Choctaw, and Big Mineral Creeks, where sections of from fifty to sixty feet have been measured. It occurs also on Red River, Fannin and Lamar Counties. The estimated thickness of the group in this part of the State is about one hundred and fifty feet, but we have not seen the base of the formation."

Fossils are exceedingly abundant in the septaria and nodules, and so far as I have been able to learn they belong to hitherto undescribed species. From the collections of Dr. G. G. Shumard I have been able to characterize the following: *Ammonites Swallovii*, *A. inæquiplicatus*, *A. Meekianus*, *A. Graysonensis*, *Ancyloceras annulatus*, *Scaphites vermiculus*, *Baculites gracilis*, *Cytherea Lamarensis*, *Tapes Hilgardi*, *Gervilia gregaria*, *Nucula Haydeni*, *Panopæa subparallela*, *Corbula Graysonensis*, *C. Tuomeyi*, *Inoceramus capulus*, and *Inoceramus*, n. sp. Fossil wood is also quite common at several of the localities visited.

The section contains what have been called grave discrepancies by another writer,[1] and from my residence in the State I think the criticism well founded. Why these errors appear in Shumard's section is easily explained. It is a composite one, made up at the city of Austin from the observations of three geologists working in widely separated portions of the State, and influenced by his predilection towards Roemer's opinions. His Comanche Peak series is evidently the same as Roemer's Fredericksburg subdivision, his Austin Limestone is Roemer's Kreidebildungen am Fusse des Hochlandes, and his Washita Limestone is the same as described by his brother and Mr. Jules Marcou. The lower part of his section is based upon the observations of his brother along Red River, where the lithologic and paleontologic variations are different from those of synchronous formations of other parts of the State. Dr. Riddell, assistant geologist, studied the formations in Bosque County, while Dr. B. F. Shumard himself studied them at Austin. He arranged, as he thought the data warranted, these observations of his brother on Red River, those of Dr. Riddell's in Central Texas, and his own and Dr. Roemer's near Austin to make up

[1] See "Notes on the Cretaceous and Carboniferous rocks of Texas, by Jules Marcou," Proc. Bost. Soc. Nat. Hist. Vol. VIII, pp. 86–97, 1861–1862.

the published section. From this section, by careful comparison of Roemer's work, it will be seen that he had the same fundamental opinion, to wit, that the Cretaceous of the lower land east of Austin extended under that of the table lands to the west, and that the tops of the hills (buttes) farther inland was the newest Cretaceous of the State.

Upon the publication of this section, Mr. Jules Marcou wrote a criticism of the same,[1] in which he pointed out many discrepancies in sequence of the groups and rearranged Dr. Shumard's section upon his own data, as follows:

Upper Cretaceous or Senonian.	Austin Limestone. Fish bed in sandstone (*Lamna Texana*). Blue Marl, with *Inoceramus problematicus*.	Arenaceous group with *Ostrea congesta*. Fish bed, *Lamna Texana* &c.
Middle Cretaceous or Greensand and Turonian.	Marly Clay or Red River group. Caprina Limestone. Comanche Peak group (superior part with *Exogyra Texana*). *Exogyra arietina* marl.	
Lower Cretaceous or Aptian and Neocomian.	Washita Limestone (comprising the inferior part of the Comanche Peak group, with *Gryphæa Pitcheri*). Caprotina Limestone.	
	Trias or Carboniferous.	

From my own observations in the State I am inclined to believe, notwithstanding the disagreement with older geologists, that Mr. Marcou's deduction is more in accordance with the actual relations of the strata than any other published and especially than those of Roemer and Shumard.

In the following years (1861, 1862) Dr. B. F. Shumard announced the occurrence of two more groups of the Cretaceous in Texas. The first of these was the Ripley group of Mississippi, which he announced before the Academy of Science of Saint Louis to have been found in Navarro County, Tex. The other was the Dakota sandstone, which he reported from Grayson County. He studied the first named group and identified over twenty species common to the Tippah County (Mississippi) beds and the Navarro County (Texas) beds. Concerning the alleged occurrence of the Dakota sandstone in Grayson County, he said that he based his opinion upon the occurrence of dicotyledonous leaves in the ferruginous sandy strata there,[2] of which he would speak further

[1] Proc. Bost. Soc. Nat. Hist., Vol. VIII, pp. 86–97, 1861.

[2] You will, perhaps, remember the statement in my paper on the Cretaceous strata of Texas (p. 589 of Transactions) that, although we had not succeeded in finding dicotyledonous leaves in the lower Cretaceous marls and sandstones of Texas, as has

at a future day, an expectation not fulfilled. These leaves, however, are now thought to be from the lower cross timbers strata, which are on a direct line of geographic continuity with the alleged Dakota of Kansas.

Dr. Shumard died without incorporating these later additions into his geologic sections. If he had done this it would have been necessary to revise the relative position of the strata entirely. He deserves credit, however, for some points which are not dwelt upon in his writings; one of these is the correlation of the groups of other States with those of Texas. He was the first to prove conclusively that the Cretaceous of the other Gulf States[1] was represented in Texas and also to intimate the occurrence there of the Dakota sandstone.[2]

Dr. R. H. Loughridge, in his sketch of the geology of the State,[3] shows clearly the occurrence of the Gulf States formation along the eastern portion of the Cretaceous areas of Texas, and traces it to the line of the Red River, north of which it had been identified and studied by D. D. Owen, in Arkansas, many years before.

From the observations of all these geologists the following is at present known concerning the Texas Cretaceous:

(1) It has been studied hastily and independently along three widely separated, parallel cross sections, to wit, by Dr. G. G. Shumard and by Jules Marcou along the northern borders, by Dr. Ferdinand Roemer and by Dr. Benjamin F. Shumard in the central (Austin and New Braunfels) region, and by Arthur Schott along the Rio Grande. The section as studied by the last mentioned, being the continuation of Mexican geologic features into Texas, has but slight resemblance to the Cretaceous of the rest of the State, so far as it has been studied.

Concerning the rest of the State two diverse opinions have been presented, especially concerning the order of sequence and the correlation of the Cretaceous strata of most of the State of Texas, one of which is based upon observations of a cross section south of Austin across the

been done by Meek and Hayden in Nebraska and Kansas and Newberry in New Mexico, they would probably be found in this position. I have now the pleasure of informing you that further explorations in Lamar County, near the Red River, have resulted in the discovery, by Dr. G. G. Shumard, of numerous impressions of leaves in alternations of yellowish sandstones and bluish shales which are believed to occupy a position below the Marly Clay or Red River group of my section, and which we regard as being on a parallel with the lower beds of No. 1 of the Nebraska section. The collection made by Dr. G. G. Shumard contains several species of monocotyledonous leaves which appear to belong to the genera Salix, Ilex, Laurus, &c. I am unable to determine positively the generic affinities of these leaves, for want of proper works of reference, but shall submit the collection to a competent fossil botanist, and think they will be found analogous to those discovered by Meek and Hayden at the base of their Nebraska section. (Trans. Acad. Sci. St. Louis, Vol. II, p. 140. Read Nov. 5, 1860.)

[1] Trans. Acad. Sci. Saint Louis, Vol. II, p. 152, 1861, and Proc. Bost. Soc. Nat. Hist., Vol. VIII, pp. 188–205, 1861.

[2] Trans. Acad. Sci. St. Louis, Vol. II, pp. 140, 141.

[3] Tenth Census: Report on Cotton Production in the United States, Vol. V, Part I, pp. 653–829. Report on the Cotton Production in the State of Texas, 1884.

eastern escarpment of the central region while the other is based upon a cross section along the northern border of the State. The first of these opinions, formulated by Roemer and reiterated by Dr. B. F. Shumard, makes the eastern division of the Cretaceous (the Gulf series) the oldest and the northwestern the newest, and correlates the whole with European strata later than the Gault.

The other opinion, and the one hitherto least accepted, partially on account of its manner of presentation, is that the Cretaceous strata are exposed in descending series in going from east to west, and that the limestone group is of the Neocomian age instead of Senonian, or White Chalk, as asserted of these strata farther south by Roemer and the Shumards. This is the opinion of Jules Marcou, as briefly expressed in 1858, and I think it the most plausible.

Concerning the extent of this formation in Texas much has been given. Roemer platted the eastern boundary from Clarksville, Red River, to near Laredo, on the Rio Grande. This boundary has not been changed by more recent observations, but rather confirmed.[1] The Cretaceous has been reported west of this line far beyond the western boundary of the State, being interrupted only where it has been denuded from above the Paleozoic and early Mesozoic areas.

It is also very well demonstrated that the eastern portion of this Cretaceous is a continuation of the Rotten Limestone and probably other subdivisions of the Cretaceous from the other Gulf States; that in the central portion of the State there is a lower division from which the overlying strata have been eroded, which is unique and probably older than the marine Cretaceous of the United States and different from them; and that along the lower Rio Grande there is an elongated area of coal bearing strata, which Mr. Schott denominates late Cretaceous and which has marked paleontologic affinities with the Upper Cretaceous of the Northwestern States and Territories.[2]

[1] Dr. R. H. Loughridge gives the eastern boundary of the Cretaceous a great western deflection from San Antonio to Eagle Pass. This is a mistake, founded primarily on an error of Conrad's, whereby he gave the wrong localities to certain Tertiary fossils, now known to be from the vicinity of Laredo. See p. 85; also, Tenth Census, Vol. V, Part I, Report on Cotton Production in Texas.

[2] There is reason to believe that these late Cretaceous coals underlie much of the Rio Grande, trans-Pecos, and Upper Canadian regions of the State. They have been recently reported all along the Rio Grande between Laredo and El Paso, at White Oaks, New Mexico, and at other places. They are probably the same coals of which Dr. Edward Hitchcock speaks in his Report accompanying Exploration of the Red River of Louisiana in the year 1852, by Randolph B. Marcy, captain Fifth Infantry. 1854, 33d Congress, 1st session, House of Reps. Ex. Doc., Appendix D, p. 144. He says: "I ought to have mentioned that among the specimens in my hands is one of lignite, collected July 3 near the sources of Red River, not far from the Llano Estacado and within the limits of the gypsum deposit to be described. It is an exceedingly compact coal and burns without flame, emitting a pungent but not bituminous odor. It is doubtless Tertiary or Cretaceous, but I think, if in large masses, it might easily be mistaken for anthracite."

THE SO-CALLED LARAMIE.

No observations of the true brackish water Laramie formation, which marks the transition from Cretaceous to Tertiary in the West, have been recorded from Texas. The term has been misapplied[1] to the lignitic strata at the base of the Gulf Tertiary in Eastern Texas, but this is not the true Laramie of the West. That the same species of vegetation grew along the coast of the marine waters of the old Gulf of Mexico as well as of the great Laramie basin in the interior of the continent is more than probable, but the term Laramie is a local group name and is not applicable to the synchronous subdivisions of the marine Cretaceo-Tertiaries.[2]

That the true Laramie may occur in the trans-Pecos region is not improbable, but it has not as yet been so recorded.

THE TERTIARY.

But one area of Tertiary formations has been positively identified in Texas, and that is the continuation of the Gulf States (marine) Tertiaries from Louisiana and Arkansas into its northeastern borders. Prof. Angelo Heilprin[3] has said nearly all that can be said of them. He remarks:

> The Tertiary formations of this State are yet too imperfectly known to admit either of an absolute localization of the various boundary lines or of an accurate subdivision into the minor geological groups. It may be safely assumed, however, from the geological conformation of the neighboring States, that all, or nearly all, of the divisions ranging from the Eolignitic to the Grand Gulf, inclusive, are represented, and that the positions occupied by these follow each other in regular succession, beginning with the oldest, from the interior coastward, with a general dip to the southeast or east. The geological notes on this region by Schott, Hall, and Conrad, and of Shumard and Buckley are exceedingly meager and unsatisfactory, and give us barely more than a general idea as to where the Tertiary formation exists.
>
> According to Dr. Loughridge, who, more than any other geologist, has closely investigated the outcrops of the different formations occurring throughout the State, the Cretaceo-Tertiary boundary line starts on the northeast from the Red River at a point a few miles above Texarkana, on the Arkansas frontier, and, taking a general southwestern direction, passing at or near Clarksville, Red River County; Corsicana, Navarro County; Marlin, Falls County; Cameron, Milam County; Elgin, Bastrop County; Seguin, Guadalupe County; and the northwest corner of Atascosa, crosses the Rio Grande at about the mouth of Las Moras Creek.

Professor Heilprin also says (p. 38) that the "westerly deflection, indicated as beginning a few miles south of San Antonio and extending to the Rio Grande, can scarcely be said to be definitely proved as yet, although Loughridge affirms that 'the glauconitic sandstones mentioned

---

[1] On the Zoölogical Position of Texas, by Edward D. Cope. Bull. U. S. Nat. Mus., No. 17, p. 5, Washington, 1880.

[2] In justice to Professor Cope it is but fair to state that this is more of a difference of opinion as to nomenclature than as to geologic time.

[3] Contributions to the Tertiary Geology and Paleontology of the United States, by Angelo Heilprin, pp. 37 et seq., 1884.

by Mr. Schott as occurring along the river [Rio Grande] from the Cretaceous rocks at the mouth of Las Moras Creek, north of Eagle Pass, southward to Roma, near Rio Grande City, are doubtless of Tertiary age.' Further evidence is needed on this point, however, although some confirmation of the supposition is lent by the discovery of Tertiary fossils (*Cardita planicosta* among others) in a locality (Arroyo las Minas), situated between El Paso and Leon."[1]

I have carefully studied the literature and the facts concerning this supposed western deflection of the Tertiary strata as reported by Loughridge in Texas and accepted by McGee in his map of the United States accompanying the Fifth Annual Report of the U. S. Geological Survey. The first recorded boundary between the Cretaceous and the marine Tertiary was that made by Roemer in his writings before mentioned. It was practically the same as that of Loughridge, without this western deflection, and made the Cretaceous end on the Rio Grande near Presidio del Rio Grande, a short distance above Laredo. The work of the United States and Mexican boundary survey is misinterpreted through a small error of Conrad, who in his published description states that the *Cardita planicosta* comes from Arroyo las Minas, a small creek in what is now Zavalla County. The label pasted upon the original type specimen of this fossil,[2] in Mr. Arthur Schott's handwriting, as identified by his son, Albert L. Schott, reads as follows: "Cretaceous ridges next to the Arroyo Sufre, in the vicinity of Mier, Mexico. Schott, October, 1853." Hence it is presumable that this fossil is valueless for determining the alleged western deflection. Dr. Loughridge's other data for making this change in the accepted map is his belief that certain strata described by Schott as Cretaceous are Tertiary. I have described these strata on page 76, and from personal observation, as well as from much paleontologic material in the U. S. National Museum, I know them to be Cretaceous. Among the fossils described from them by Conrad, and with locality labels pasted upon them by Schott, are the following from Jacun, three miles east of Laredo:[3] *Ammonites pleurisepta*, *Exogyra costata*, *Inoceramus cripsii* Mantell, *I. Texanus* Conrad, *Ostrea crenulimargo* Roemer, *Dosina*, *Turritella*, *Natica*, and *Ammonites pleurisepta* Con.[4] These fossils are positively known to belong to the Cretaceous, and the locality where they occur is one hundred and fifty miles east of the boundary of that formation as deflected by Dr. Loughridge.

The *Exogyra costata* and *Inoceramus cripsii* are characteristic fossils of the Upper Cretaceous of all the Gulf States, and the *Ammonites pleu-*

[1] Report U. S. and Mex. Boundary Survey, Vol. I, Part II, pp. 141 and 161.

[2] Now in collection of the U. S. National Museum.

[3] Report on U. S. and Mex. Boundary Survey, Vol. I, Part II, p. 143.

[4] Ibid., p. 159. This species is described under the name of *Ammonites pleurisepta*, but figured (Plate XV) as *A. pedernalis*.

risepta of Conrad is a typical fossil of the peculiar formation which Mr. Schott described and is now known to be very late Cretaceous. Even were it not for the original label pasted on the *Cardita planicosta*, alleged to be from Arroyo las Minas, a glance at the fauna among which it is placed by Mr. Conrad[1] would be sufficient to show that it is a stray specimen, for the rest are all typical Cretaceous forms. Instead of this western deflection of the Tertiary in Texas I am of the opinion, from the evidence we have, that it is many miles to the east of Laredo.

This eastern or Gulf Tertiary has been recognized as such by several authors under many names. Roemer noted the presence of beds similar to those at Fort Claiborne, Ala., and after a revision of all the printed evidence it is to be doubted whether much more is known about the Tertiary in Texas than is implied in his remark and noted on his map, to wit:

> It is hardly to be believed that this Tertiary formation of Texas is to be found exclusively in the country of the Brazos [where he observed it]. It occupies a very similar zone to the Tertiary of Alabama, Mississippi, and other States, and like it, at most places is at the foot of the Cretaceous to the west and covered to the east by diluvial strata. (Texas, p. 372.)

Several other areas of the Tertiary have been reported besides this continuation of the Gulf group. The principal of these are the two anomalous forest regions known as the cross timbers. Dr. S. B. Buckley calls these Tertiary, Miocene, Eocene, &c. in his reports, but his evidence, as stated, is not such as to warrant his deductions.

The stratigraphy of the Tertiary in Texas has been neglected entirely, and we have nothing concerning its exact relation to the Cretaceous below or to the later formations. Neither is there any information concerning the stratigraphy of the group itself. In fact, the development of these strata is still to be made. All that can possibly be said of it at present is that it possesses certain broad resemblances to the Tertiary of the other Gulf States and that it consists of unstudied strata, lignitic at the base and ferruginous higher up. It rests upon the Cretaceous strata, but no evidence has been taken to ascertain whether it is simply a continuation of the sedimentation of that period or whether there is a non-conformity between them. Neither is there any evidence concerning its relation to the post-Tertiary strata.

QUATERNARY AND OTHER POST-TERTIARY STRATA.

Very little is known concerning the surface geology of Texas or of the later formations, but it is apparent that the great deposits of the coastal region result from the erosion of the interior surface. Dr. Ferdinand Roemer wrote the most of what we now know of these formations. He divides the coastal region of Texas into the alluvial and the diluvial region and describes the character of the drift and depositions of each.

[1] *Ostrea carinata* Lam., *O. anomiæformis* Roemer, *Neithia occidentalis* Con. Report U. S. and Mex. Bound. Survey, Vol. I, Part II, p. 143.

He showed that there was considerable very recently made land extending for a varying distance inland from the coast, and that it was so recent in deposition that it contained at Houston, 50 miles inland, the fossil shells whose living representatives are found in the bay of Galveston. He also describes with much clearness certain of the older drifts, but his descriptions are purely local. Dr. R. H. Loughridge notes the occurrence of Quaternary stratified drift as composing the arenaceous, cross timber region of Central Texas, and other writers have noted the drift of the lower Brazos, Red, and Colorado Rivers. The various papers of the United States and Mexican boundary survey reports describe several peculiar drift formations of the Rio Grande along its course from its mouth to El Paso. The presence of a fine, decomposing mass of pebbles over the gypsum beds has also been mentioned by writers on that region. In fact, the literature is full of fragmentary reference to local superficial formations, which we are left to presume to be of any age we please, but absolutely nothing has been done towards classifying these phenomena. It is well known that the "red rises" of the great rivers of the Texas region have been carrying down their loads of sediment, taken from the receding escarpment of the plains among which they rise, and depositing them in the lagoons along the coast. The richest sugar lands of Louisiana and Texas have been built up in this manner, in almost recent times, and the vastness of the process is grand and impressive beyond expression. No other theme is so promising to the future geologist in the region under discussion as the subject of the laws of distribution and the age of the post-Cretaceous formations of Texas

GEOLOGICAL DEDUCTIONS.

From these fragmentary writings we can only make the following general deductions concerning the geology:

The Cambrian and Pre-Cambrian strata probably underlie the State and extend as far west as the Grand Cañon of the Colorado. Upon these are deposited Lower Silurian rocks, with occasional outcroppings in the limited central and trans-Pecos areas. The Devonian strata are absent. The Carboniferous strata present two phases and are in two widely separated areas, the first being a continuation of the Missouri coal fields through Indian Territory into Northern Texas and the other being a continuation of the non coal bearing strata from the great West. Little is known of the intimate relations of the strata between the well defined Carboniferous and the Cretaceous, but there are many ideas concerning them: (1) The older Mesozoic, consisting of an extensive deposit west of the ninety-ninth meridian, extending all the way, perhaps, from the typical Coal Measures of the Carboniferous to the well defined fossiliferous lower Cretaceous. This group comprises the gypsum bearing strata, and has been called in our literature Permian, Permo-Carboniferous, Triassic, Jura-Trias, and the Dakota group of the Cretaceous. The minute stratigraphy of these strata has never been studied and their exact age is still an unsolved problem. (2) The fossiliferous Lower Cretaceous, being easily distinguished everywhere by its unique lithologic and paleontologic characters. It overlies nearly all of the older formations, the latter being exposed usually by the erosion of its strata. Concerning the character and extent of this formation very little is known, and it is only determinable by the peculiar individuality of its fauna and the interpretation of Mr. Jules Marcou's description of a small local outcrop. It can only be said that this formation does exist, that it is older than all writers except Mr. Marcou have made it, and that its extent seems to be confined to the portion of Texas west of the black prairie region and indeterminately southward into Mexico. The higher divisions of the Cretaceous immediately overlie this. These have been traced directly from the older Gulf States, and, like the succeeding Tertiaries, seem to represent the earlier stages of the contracting shores of the present Gulf of Mexico. The Tertiaries are generally conceded to be merely a continuation of the Tertiaries of the older Gulf States, with local variations. The coast of the Gulf of Mexico of to-day is a continuation of the results of the same forces in operation since Middle or early Cretaceous time, so far as can be ascertained by interpretation of all the evidence.

GENERAL CONCLUSIONS.

Only a word is necessary to express the net results of all the observations described in the previous pages. The following facts are obvious:

(1) There is no accurate knowledge of the essential topographic features of Texas upon which geologic work can be based.

(2) The geologic work has been fragmentary, unconnected, uncorrelated, and unsystematic throughout. It has been mostly descriptive paleontology instead of stratigraphic work.

(3) There has been very little accurate stratigraphic work recorded.

(4) Most of the literature deals with broad generalities rather than with specific description.

It is evident that very little of the work deserves to be classified above preliminary reconnaissance and that the need of the future is apparent: the careful study of typical sections by combined stratigraphic and paleontologic data, the tracing of the extent and variation of these features, and, first of all, a correct and reliable topographic survey of the entire State. There is not on record a clear and intelligible section of a single local area.

In the preceding pages I have tried to prepare the way for honest students to take up the work without long years of weary research in endeavoring to find out what has been done in this great region. No portion of our country is more pregnant with unstudied features of geologic interest. Important relations in the history of the continent have been traced to its borders on every side and stopped there by a want of minute knowledge of its formations. To the student who will undertake the solution of a single one of the questions involved the reward will be results of incalculable value. Among these problems are the history of the river systems, the elevation of the land features from the sea, the effects and the results of subaërial erosion, the intimate features of the stratigraphy, the tracing of ancient interior continental shore lines, the history of the recession of the escarpment lines (especially that of the Llano Estacado), the building up of the coast by the sedimentation resulting from this erosion, the accurate enumeration and distribution of typical faunas, and the stratigraphic position of its fossils, and, chief of all, the deduction from these scientific determinations of those economic results appertaining to agriculture, industry, and commerce without which the true possibilities and impossibilities of the great region will forever remain unknown and its development depend upon blind and costly experiment.

INDEX.

A.

B.

C.

Page.

D.

E.

F.

G.

H.

J.

K.

L.

M.

N.

O.

P.

T.

U.

W.

o

ADVERTISEMENT.

[Bulletin No. 46.]

The publications of the United States Geological Survey are issued in accordance with the statute approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

Except in those cases in which an extra number of any publication has been supplied to the Survey by special resolution of Congress or has been ordered by the Secretary of the Interior, this Office has no copies for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report of the United States Geological Survey to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Second Annual Report of the United States Geological Survey, 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xxxii, 473 pp. 85 pl. and maps.

V. Fifth Annual Report of the United States Geological Survey, 1883–'84, by J. W. Powell. 1885. 8°. xxxvi, 469 pp. 58 pl. and maps.

VI. Sixth Annual Report of the United States Geological Survey, 1884–'85, by J. W. Powell. 1886. 8°. xxix, 570 pp. 65 pl. and maps.

The Seventh and Eighth Annual Reports are in press.

MONOGRAPHS.

Of the Monographs, Nos. II, III, IV, V, VI, VII, VIII, IX, X, XI, and XII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt. U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. Copper-Bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price $1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price $1.05.

VII. Silver-Lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price $1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price $1.10.

16. On the Higher Devonian Faunas of Ontario County, New York, by John M. Clarke. 1885. 8°. 86 pp. 3 pl. Price 5 cents.

17. On the Development of Crystallization in the Igneous Rocks of Washoe, Nevada, by Arnold Hague and Joseph P. Iddings. 1885. 8°. 44 pp. Price 5 cents.

18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Charles A. White. 1885. 8°. 26 pp. 3 pl. Price 5 cents.

19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. 28 pp. Price 5 cents.

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. 114 pp. 1 pl. Price 10 cents.

21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. 16 pp. 5 pl. Price 5 cents.

22. On New Cretaceous Fossils from California, by Charles A. White. 1885. 8°. 25 pp. 5 pl. Price 5 cents.

23. Observations on the Junction between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point, Lake Superior, by R. D. Irving and T. C. Chamberlin. 1885. 8°. 124 pp. 17 pl. Price 15 cents.

24. List of Marine Mollusca, comprising the Quaternary fossils and recent forms from American Localities between Cape Hatteras and Cape Roque, including the Bermudas, by William H. Dall. 1885. 8°. 336 pp. Price 25 cents.

25. The Present Technical Condition of the Steel Industry of the United States, by Phineas Barnes. 1885. 8°. 85 pp. Price 10 cents.

26. Copper Smelting, by Henry M. Howe. 1885. 8°. 107 pp. Price 10 cents.

27. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1884–'85. 1886. 8°. 80 pp. Price 10 cents.

28. The Gabbros and Associated Hornblende Rocks occurring in the Neighborhood of Baltimore, Md., by George H. Williams. 1886. 8°. 78 pp. 4 pl. Price 10 cents.

29. On the Fresh-water Invertebrates of the North American Jurassic, by Charles A. White. 1886. 8°. 41 pp. 4 pl. Price 5 cents.

30. Second Contribution to the Studies on the Cambrian Faunas of North America, by Charles D. Walcott. 1886. 8°. 369 pp. 33 pl. Price 25 cents.

31. A Systematic Review of our Present Knowledge of Fossil Insects, including Myriapods and Arachnids, by Samuel H. Scudder. 1886. 8°. 128 pp. Price 15 cents.

32. Lists and Analyses of the Mineral Springs of the United States; a Preliminary Study, by Albert C. Peale. 1886. 8°. 235 pp. Price 20 cents.

33. Notes on the Geology of Northern California, by Joseph S. Diller. 1886. 8°. 23 pp. Price 5 cents.

34. On the relation of the Laramie Molluscan Fauna to that of the succeeding Fresh-water Eocene and other groups, by Charles A. White. 1886. 8°. 54 pp. 5 pl. Price 10 cents.

35. The Physical Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1886. 8°. 2 pp. Price 10 cents.

36. Subsidence of Fine Solid Particles in Liquids, by Carl Barus. 1887. 8°. 58 pp. Price 10 cents.

37. Types of the Laramie Flora, by Lester F. Ward. 1887. 8°. 354 pp. 57 pl. Price 25 cents.

38. Peridotite of Elliott County, Kentucky, by Joseph S. Diller. 1887. 8°. 31 pp. 1 pl. Price 5 cents.

39. The Upper Beaches and Deltas of the Glacial Lake Agassiz, by Warren Upham. 1887. 8°. 84 pp. 1 pl. Price 10 cents.

40. Changes in River Courses in Washington Territory due to Glaciation, by Bailey Willis. 1886. 8°. 10 pp. 4 pl. Price 5 cents.

41. Fossil Faunas of the Upper Devonian—the Genesee Section, New York, by Henry S. Williams. 1886. 8°. 121 pp. 4 pl. Price 15 cents.

42. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1885–'86. F. W. Clarke, chief chemist. 1887. 8°. 152 pp. 1 pl. Price 15 cents.

43. On the Tertiary and Cretaceous Strata of the Tuscaloosa, Tombigbee, and Alabama Rivers, by Eugene A. Smith and Lawrence C. Johnson. 1887. 8°. 189 pp. 21 pl. Price 15 cents.

44. Bibliography of North American Geology for 1886, by Nelson H. Darton. 1887. 8°. 35 pp. Price 5 cents.

45. Present Condition of Knowledge of the Geology of Texas, by Robert T. Hill. 1887. 8°. 94 pp. Price 10 cents.

Numbers 1 to 6 of the Bulletins form Volume I; Numbers 7 to 14, Volume II; Numbers 15 to 23, Volume III; Numbers 24 to 30, Volume IV; Numbers 31 to 36, Volume V; Numbers 37 to 41, Volume VI; Numbers 42 to 46, Volume VII.

The following are in press:

46. The Nature and Origin of Deposits of Phosphate of Lime, by R. A. F. Penrose, jr.

47. Analyses of Waters of Yellowstone National Park, by F. A. Gooch and J. E. Whitfield.

48. On the Form and Position of the Sea Level, by R. S. Woodward.

49. On the Latitude and Longitude of Points in Missouri, Kansas, and New Mexico, by R. S. Woodward.

50. Invertebrate Fossils from California, Oregon, Washington Territory, and Alaska, by C. A. White.

51. On the Subaërial Decay of Rocks and the Origin of the Red Color of Certain Formations, by Israel C. Russell.

52. Geology of the Island of Nantucket, by N. S. Shaler.

In preparation:

— Notes on the Geology of Southwestern Kansas, by Robert Hay.

— On the Glacial Boundary, by G. F. Wright.

— The Gabbros and Associated Rocks in Delaware, by F. D. Chester.

— Fossil Woods and Lignites of the Potomac Formation, by F. H. Knowlton.

— Mineralogy of the Pacific Coast, by W. H. Melville and Waldemar Lindgren.

— Report of Work Done in the Division of Chemistry and Physics, mainly during the fiscal year 1886-'87.

— A Report on the Thermo-Electrical Measurement and High Temperatures, by Carl Barus.

— The Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan, by George H. Williams; with an Introduction by R. D. Irving.

— Bibliography of the Paleozoic Crustacea, by A. W. Vogdes.

STATISTICAL PAPERS.

A fourth series of publications, having special reference to the mineral resources of the United States, has been undertaken.

Of that series the following have been published:

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Mineral Resources of the United States, 1885. Division of Mining Statistics and Technology. 1886. 8°. vii, 576 pp. Price 40 cents.

Mineral Resources of the United States, 1886, by David T. Day. 1887. 8°. viii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1887, by David T. Day. 1888. 8°. Price — cents.

In preparation:

Mineral Resources of the United States, 1888, by David T. Day. 1889. 8°.

The money received from the sale of these publications is deposited in the Treasury, and the Secretary of that Department declines to receive bank checks, drafts, or postage stamps. All remittances, therefore, must be by POSTAL NOTE or MONEY ORDER, made payable to the Librarian of the U. S. Geological Survey, or in CURRENCY, for the exact amount; and all correspondence relating to the publications of the Survey should be addressed

TO THE DIRECTOR OF THE
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

WASHINGTON, D. C., *November* 1, 1888.

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 46

WASHINGTON
GOVERNMENT PRINTING OFFICE
1888

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

NATURE AND ORIGIN

OF

DEPOSITS OF PHOSPHATE OF LIME

BY

R. A. F. PENROSE, Jr.

WITH AN

INTRODUCTION BY N. S. SHALER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1888

CONTENTS.

ILLUSTRATIONS.

INTRODUCTION.

By N. S. Shaler.

The circumstances which have led to the preparation of the subjoined report on mineral phosphates are as follows, viz: In 1870 the present writer was employed by the Superintendent of the Coast Survey, the late Benjamin Peirce, to examine the phosphate beds of South Carolina with a view to determining the limits of that field; it was also deemed desirable to ascertain, if possible, the conditions which led to the formation of the deposits.

It was at that time the intention of Professor Peirce to have the geology of the belt of country within the limits of the Coast Survey maps carefully determined, so that they might be shaped in a way that would better serve the commercial interests of the country and also have a greater scientific value. After a time it appeared that there were legal difficulties in the way of publishing these studies in the reports of the Coast Survey and this work was suspended. It was the hope of Professor Peirce to secure a modification of the law, but before this was accomplished he retired from the post of Superintendent and his successor deemed it best to abandon the project. During the two years in which I was engaged in this work on the geology of the coast line I became very much interested in the problems connected with the origin and distribution of phosphatic deposits. From 1873 to 1880, while employed as State geologist of Kentucky, I had a chance to see a good deal of the somewhat phosphatic limestones of the Cambro-Silurian sections, a set of beds which, by their decay, have given great fertility to the soils that lie upon them. The researches of Dr. Robert Peter, the chemist of that survey, made it plain that the phosphatic contents of the soils are among the first materials to be exhausted by the careless tillage which characterizes our American agriculture, and that they are the most costly to restore to the soil.

Extending the general inquiry to the grain-producing districts which lie to the north and west of Kentucky, it became evident that all those States, which are now the granary of this country and the chief source of supply for European markets as well, are rapidly exhausting their soils and will soon be in grave need of phosphatic manures. The importance of such manures has so far been well recognized only by the cotton growers of this country, yet it is evident that in a short time this class of fertilizers will be equally in demand for all forms of grain crops.

These considerations have led me to the conclusion that the geological history of phosphatic deposits should receive more deliberate attention than has yet been given to it.

When I began my work in the U. S. Geological Survey, I asked permission of the Director to continue my studies on phosphatic deposits. There was at the time no money available for these studies; it was therefore necessary that they should be carried on without other expense to the Survey than that involved in the small share of my time which could be given to the supervision of the work. It was my good fortune, however, to find in one of my students of geology, Dr. R. A. F. Penrose, jr., a person who was willing at his own cost to undertake a preliminary study of the whole field as far as our knowledge extends and thus to prepare the problems concerning American phosphate deposits for detailed inquiry. This work he has pursued with great intelligence and energy during the two years in which he has been engaged in it. In this task he has examined all the known phosphate deposits of the United States and Canada and has made a careful inquiry into the literature of the subject, as is shown by the extended bibliography which is appended to this report.

The object of this work being to make a necessary preparation for the further study of the American phosphatic deposits, Dr. Penrose's studies were not designed to be encyclopedic in their scope, but rather to afford a synopsis of what is known of the deposits in this and other countries. So little is yet generally known of the several conditions under which these deposits may occur that it would be very blind work to search for them in this country without a careful endeavor to bring together the experience which has been gained in other countries. It will be evident to the reader of Dr. Penrose's report that the workable deposits of phosphates are found in a greater variety of circumstances than those which contain most mineral substances that have an economic value. It is not likely that we have as yet exhausted the inquiry into the modes of occurrence of this substance; but this synopsis of the experience in this and other countries, which is much more extensive than any other which has been published, will, I believe, serve as a guide to the further search for sources of supplies of phosphatic manures. It will also be evident to the reader that the conditions of occurrence of these deposits in Europe make it plain that the search for them in this country may advantageously be directed to many districts in which they have not as yet been found.

So far the vein deposits of apatite, such as those which are so abundant north of the St. Lawrence, have not been found in workable quantities within the limits of the United States, though the general geological conditions of the Laurentian area exist in the Adirondack district and in the southern parts of the Appalachian system as well as in several districts of the Rocky Mountains. It would be remarkable if extensive deposits of this nature, so common in Canada and in the equivalent rocks of northern and southern Europe, should not be found at many points in our American Archæan formations. It is on this account that so much space in this report is given to the description and illustration of the Canadian apatite deposits. So, too, we may hope to find in the ancient rocks of this country deposits analogous to the great Logrosan and Cáceres veins in the province of Estremadura, Spain.

The Cretaceous deposits of Belgium (which at the present time are, next after the phosphate beds of South Carolina, the most productive in the world) present a type of beds not yet found in paying quantities in the United States, though deposits of the same age, formed under about the same conditions, abound in this country. It is not to be expected that phosphatic deposits will exactly repeat themselves in strata of the same age in widely separated regions; yet it is clear from the summary account of the geological distribution of these phosphates in Europe and North America that in the case of these, as well as in that of other substances of value in the arts, there are certain guiding principles which we may base on the stratigraphy of the deposits to aid our search. The known workable deposits of a phosphatic nature are limited to certain portions of the geological section. Beginning at the surface of the deposits now forming, these zones are, in descending order, as follows:

(1) Superficial deposits, including (*a*) those formed in the manner of guanos; (*b*) the deposits formed in the bottoms of fresh-water swamps, sometimes in connection with deposits of bog iron ore (hematite); and (*c*) deposits which are the result of the long-continued decay of rocks containing a small portion of lime phosphate intermingled with lime carbonate, as, for instance, the deposits of North Carolina. This superficial group of deposits has no other common feature save that they are on the surface and are due to causes now or recently in action.

(2) Deposits of the Tertiary and Upper Cretaceous. These deposits are generally the result of reactions which took place on ancient land surfaces, the phosphatic matter being such as formed in swamp beds or in ablation deposits like those of the Carolinas or of eastern England. Below the level of the Cretaceous no important deposits of phosphate have been found in the vast section of rocks which lies between that era and the Devonian horizons.

(3) In the horizons below the level of the Upper Silurian bedded rock phosphates and apatite deposits occur. These infra-Devonian bedded rock phosphates seem to have derived their phosphatic matter from the animals, brachiopods and small crustaceans, which separated that substance from the sea insects or other food which the old oceans afforded.

These phosphate-bearing invertebrates appear to have been particularly abundant in the early Paleozoic seas.

(4) Below the level of the Silurian the phosphatic deposits which have been worked probably belong altogether to the class of apatites or crystallized lime phosphates, and are probably all new deposits. They evidently occur through a large part of the Laurentian section, though, so far, the known deposits of economic importance are possibly limited to one portion of that vast series of rocks.

The apparent absence of phosphatic deposits of economic importance in the section between the Devonian and the Cretaceous is remarkable. It is possible that it may be due to our lack of knowledge as to the chemical character of the deposits in those parts of the earth's crust. It is more likely, however, that such deposits do not there exist, owing to the fact that the invertebrate species of animals which secrete phosphatic matter in their skeletons became relatively less abundant in the middle portion of the geological section; while the vertebrate species, the birds which accumulate guanos and the fishes which afford an abundance of bones and teeth to littoral deposits, as well as the mammalia whose skeletons occasionally form a considerable element in the later deposits, did not begin to contribute phosphatic matter to the rocks until comparatively modern times.

The absence of phosphatic deposits in the Upper Paleozoic and Lower Mesozoic strata is well shown by the fact that, while in the Carboniferous and the Triassic beds there are abundant land surfaces which have been carefully explored, no phosphatic deposits of economic importance have been found in them, while on the relatively very limited areas of the Tertiary and Cretaceous formations where old land areas have been explored a large number of deposits of beds of nodular phosphate have been found.

From the facts set forth in Dr. Penrose's report and the unpublished results of certain studies on swamps, we may draw certain general conclusions as to the best method of prosecuting the search for unknown deposits of American phosphates. These conclusions are essentially as follows:

First, as regards the superficial and recently formed deposits of phosphates. We are driven to the conclusion that this class of deposits may reasonably be sought for wherever soft calcareous beds containing a certain amount of lime phosphate have been subjected to long continued leaching by waters containing the share of carbonic acid gas which belongs to all rain-water after it has passed through the mat of decayed vegetation. As long ago as 1870 I became convinced that it was to the leaching out of the carbonate of lime by the carbonated water of the soil bed that we owe in the main the concentration of the nodular phosphates of South Carolina.[1] Although it is still necessary to explain

[1] See Proc. Boston Soc. Nat. Hist., vol. 13, 1871, p. 222.

many of the details of this process to adapt it to the peculiar circumstances of particular deposits, it seems to me that it is the key to the most common forms of superficial accumulations of nodular phosphates. In an admirable description of the phosphate beds in the neighborhood of Mons, in Belgium, by Mr. F. L. Cornet,[1] that distinguished author has independently propounded this simple hypothesis, and several other writers on the subject have apprehended the importance of this leaching action.

It is evidently essential to this process of concentration that the surface of the deposits which are leaching away should have been preserved from the action of mechanical erosion, which would have prevented the formation of phosphatic concentrates.

Inquiry into the conditions of the swamp deposits of this country has satisfied me that beneath the surface of many of our fresh-water marshes, and probably in a lesser degree beneath the marine deposits of the same nature, there is a more or less important concentration of lime phosphates constantly going on. The effect of this action is seen in the remarkable fitness of these fresh-water swamp soils for the production of grain crops. For instance, in the case of the Dismal Swamp district in Virginia and North Carolina we find that the soils on which the swamp deposit rests are extremely barren, while in the mud that has accumulated beneath the swamp we have a rich store of phosphates, potash, and soda, which causes the soil of these swamps to be extremely well suited to grain tillage as soon as it is drained. In a similar way in the swamps of New England and elsewhere we find the bog-iron ores which are frequently accumulated in their bottoms very rich in phosphatic matter. The evidence is not yet complete that this phosphatic material becomes aggregated into nodules in the swamp muds, but the number of cases in which nodules have been found in this position makes it quite likely that the nodulation of the material may go on in that position. The present condition of the inquiry goes, in a word, to show that wherever we have a region long overlaid by swampy matter we may expect a certain concentration of lime phosphates in the lower part of the marsh deposit. Wherever the swamp area lies upon somewhat phosphatic marls which have been slowly washed away by the downward leaching of the waters charged with the acids arising from decayed vegetation, or where the swamp deposits, even when not resting on such marls, are in a position to receive the waste from beds containing phosphates, we may expect to find a considerable concentration of phosphatic matter in the swamp bed. By the erosion of these swamps we may have the nodules of phosphate concentrated in beds such as occupy the estuaries of the rivers near Charleston, S. C.

The area of swamp lands which fulfill these conditions is very large. They exist in numerous areas in more than half the so-called Southern

[1] See Quart. Jour. Geol. Soc. London, vol. 42, 1886, p. 325.

States. At present it can only be said that they afford the conditions which, so far as the theory goes, should lead to the accumulation of phosphatic deposits of greater or less importance. It will be a simple matter to explain these deposits, though it is a task requiring a patient study of a large field. Although it is likely that the phosphatic materials will be found aggregated into nodules at many points in this area it will not be safe to assume that they will be found in the same form as those which occur about Charleston, S. C. The nodules found in the beds about the last named point, though in my opinion originating beneath swampy deposits, have apparently been, in part at least, swept from their original beds by the rivers which enter the sea at that point and have thus been concentrated in estuarine deposits.

Although local concentrations of phosphatic nodules other than those now known may well be sought for in the Southern States, I do not think that the precise conditions or character of the deposits as found at Charleston should be expected to repeat themselves elsewhere. It is characteristic of the process of concentration of phosphatic, as well as of other matter into nodules that the material takes on a great variety of aspects, each proper to a particular site, and this although the surrounding circumstances of the several localities may apparently be identical.

Next lower on the geologic section we have, in the Tertiary region of the Mauvaises Terres, extensive deposits of vertebrate remains which may possibly yield some commercially important supplies of bone phosphates. Although none of the existing sources of supply of these materials come from deposits of the nature of those found in Nebraska, the conditions of that remarkable region are so peculiar that it will not be well to pass it by without inquiry.

While the American Cretaceous deposits are, as a whole, decidedly different from those of the Old World, the Greensand beds of the section in the two countries present considerable likeness in their characters. It is probable that in this country, as in Europe, considerable parts of the Cretaceous section are somewhat phosphatic, and that those beds containing disseminated phosphatic matter have been in many places exposed to the process of leaching in former geologic periods. Therefore we may reasonably search in the Cretaceous beds of this country for the same class of phosphatic deposits which have proved so important in the northern parts of Europe.

Although some peculiar deposits of phosphate have been found in the Devonian rocks of Nassau, it may safely be assumed that below the line of the Cretaceous we have no facts to guide us in our search for phosphates until we come to the horizon of the Upper Silurian limestones, at about the level of the uppermost beds of the Upper Silurian, as far as that level can be determined by the perplexing assemblage of fossils. There occurs in Bath County, Ky., a thick bed of much decayed, very phosphatic siderite. This deposit covers but a small area and consists of a patch of limestone about fifteen feet thick, which has been converted into siderite by the inleaching of iron-bearing waters from the ferruginous Ohio (Devonian) shales which formerly overlaid the bed. Since the escarpment of the Ohio shales retreated beyond this bed it has been subjected to oxidation and is now in the main converted into a much decayed limonite. Beneath this limonite there is a greenish, argillaceous sand which contains frequent nodules of lime phosphate. These nodules are smooth-surfaced and not unlike some of the nodules from the Carolina district. They contain as much as 92 per cent. of lime phosphate. It seems likely that these nodules were formed by the leaching out of the lime phosphate from the overlying ferruginous layers, which has completely removed the lime carbonate, but has not removed the whole of the less soluble lime phosphate (Fig. 1).

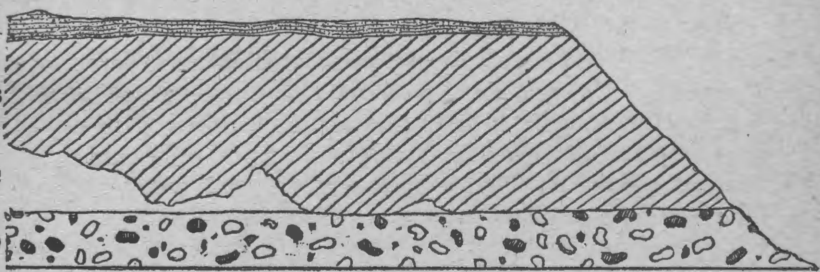


FIG. 1. Section at Olympia, Bath County, Ky. (Preston ore bed). A, soil; B, limonite iron ore; C, siderite iron ore; D, phosphatic nodules. Scale: 1 inch = 12 feet.

Although this deposit of nodules is not of sufficient abundance to have any economic value, it is clear that we have in it an indication of a method where, by a slight variation of the conditions, important beds of nodular phosphates might be found.

In the horizons of the Cambro-Silurian section, or, as it is generally called, the Lower Silurian, there is much greater reason to expect the occurrence of workable phosphates than in the beds immediately above. It is likely that the most important of the Spanish deposits belong in strata of this period, and the Welsh deposits of this general age are of noteworthy extent. We know, moreover, that the commoner marine animals of this part of the geological section were particularly adapted for the secretion of lime phosphate.

The search of this portion of the section for phosphates should be directed to two ends: first, to finding beds of very phosphatic limestone; and, second, to discovering veins formed by a segregation of lime phosphates either in the form of the Spanish deposits referred to by Dr. Penrose or in the condition of nodular accumulations. The area of rocks of these Lower Silurian and Cambrian periods in this country is very extensive, and so far there has been no search of them for phosphatic materials. The little work done in Kentucky during the above-mentioned geological survey served only to show that the proportion of lime phosphate in the rocks is extremely variable, and that in certain beds it is so considerable that the material might advantageously be used in a local way for fertilizing purposes.[1]

The search for phosphatic materials in the stratified rocks demands a method of inquiry that has not yet been applied to the study of our rocks. It seems to me that the method, or rather methods, should be as follows:

First, there should be a careful inquiry to determine the share in which the several important groups of rock-making organic forms contribute phosphatic matter to strata. This can be accomplished by carefully comparing the chemical character of particular strata with the fossils the beds contain. When this determination is made we shall have one means of guiding our inquiries, which will surely be of great value in the search for bedded phosphates.

Secondly, we should have a carefully executed chemical survey of our stratified rocks. Enough can be gathered from the scattered records of chemical analysis to make it plain that certain features of the chemical character of particular beds or divisions of strata often extend laterally for great distances. This is shown in a general way by the character of the soils formed of the waste of particular horizons; for instance, the deposits of the horizon on which lies the Cincinnati group of this country and the equivalent deposits of Europe are nearly always well suited to grasses and grains and have a great endurance to tillage. It is now desirable to take these beds which promise to afford mineral manures and subject each stratum to analyses which shall determine the quantity of phosphoric matter, soda, and potash which they contain, so that their fitness for use as mineral manures may be ascertained.

Below the level of the Silurian and Cambrian strata, and partly in those sections where they have been much metamorphosed, lies the field of the vein phosphates. It is more than likely that in this vast thickness of rocks with their development in this country there are many extensive sources of this class of phosphates which await discovery. As yet no careful search has been made for such veins in any part of the United States. The regions most likely to contain such deposits are found in the central parts of the Appalachian system of mountains,

[1] Among the analyses recently made by the chemists of the Kentucky geological survey is one which indicates the presence of phosphoric acid in considerable quantities in the limestones of Corniferous age exposed at Stewart's mill, on Lulbegrud Creek, in Clark County. This partial analysis, for which I am indebted to Mr. John R. Proctor, the present director of the Kentucky survey, is as follows, viz:

Lime carbonate	21.380
Magnesia	3.055
Phosphoric acid	9.710
Potash	.830
Soda	.228
Siliceous nodules insoluble in acids	27.580

especially in the section from Virginia southward; in the Archæan district of Missouri and Arkansas, and in the vast region of highly metamorphic rocks of the Cordilleran district, extending from the Rocky Mountains to the Pacific Ocean. It is true that at present the economic value of phosphatic deposits in the western part of the continent would probably be small, on account of the great cost of transportation to the seaboard districts; but the growing use of phosphatic manures in the Mississippi Valley and the rapid exhaustion of the soils of that district will soon give commercial importance to any sources of supply of phosphates that may be found in any parts of the Cordilleras which are convenient to transportation.

A proper study of the mineral manures of this country can best be carried on by means of a well considered co-operation between geological explorers and the experiment stations of the several States. At present the methods of using mineral phosphates are extremely costly: not only is the material brought into the soluble condition by saturation in sulphuric acid, but it is then mingled with ammoniacal and other matter to increase its effect as a fertilizer. The result is that, although a ton of Carolina phosphate now costs but $6, the average price of the manufactured product to the consumer at the phosphate factories is about $30 per ton. It is probable that the essential value of the phosphatic ingredients to the plants of most soils is not enhanced by this costly treatment, though an incidental but dearly purchased gain, in the case of some crops, is obtained from the ammoniacal matter. The only effect of the superphosphatizing on the phosphatic matter is to make it more immediately absorbable by the plants. If placed on the soil without any other preparation than grinding, lime phosphate will slowly pass into a condition in which it may be absorbed by plants, while if treated with sulphuric acid it is for a time at least in a soluble state. That this treatment is not essential is well shown by the fact that the phosphatic matter derived from the rocks is brought into a condition for absorption by the ordinary process of decay in soils. Our present costly method of applying phosphates has come about through the commercial history of artificial manures, which is as follows:

Before guanos were brought into use the English farmers had learned that they could profitably use the phosphatic marls of their Tertiary and Cretaceous deposits without any artificial preparation. If guanos had not existed it seems likely that mineral phosphates would have always been used in this way. When the Peruvian guanos came into use they afforded a much more stimulating material than any other purchasable manures, and in a short time they established the type of commercial fertilizers. When the sources of supply of these guanos became in part exhausted, artificial compounds, formed on a basis of rock phosphates or apatites, were devised to take their place. These were made to imitate the effect of the guanos as closely as possible. Like them, they gave a quick though temporary stimulus to the soil, enabling the farmer to obtain the greater part of the return for his investment in the season following the application of the high-priced manure. Very generally the fertilizer, guano or compounded material, was applied with the seed or dibbled in the soil alongside the young plant, so that it would be immediately available in the first stages of its growth, and, what is a more important consideration, that it might take less of the substance to give the effect than if it were sown broadcast over the surface or mingled with the soil of the whole field.

In this way a habit has been established in the art of using phosphates, as well as in the composition of the material, which, like all commercial habits, is hard to overcome. The question to be determined is as to the utility of phosphates with other modes of treatment than those which are applied to the imitation guanos. At present this treatment requires the commingling of the lime phosphate with a number of costly substances. The manufacture can only be advantageously carried on at points remote from the districts where the materials are produced and remote from the fields where they are used, so that the costs of transportation are great. The problems to be solved by the agricultural stations are as follows:

(1) As to the effect, immediate as well as permanent, arising from the application of ground phosphatic rock commingled with other materials on soils used for the production of different crops.

(2) As to the degree of comminution of the material which is most advantageous. It seems possible that fine pulverizing may take the place in a measure of superphosphatizing.

(3) As to the effect of mingling the powdered rock with ordinary barn-yard manure, peat, and other similar substances.

(4) As to the effect of lime phosphate used alone on soils containing different mineral constituents, as, for instance, those having considerable proportions of lime carbonate and those having but little of that substance.

(5) As to the proportion of the lime phosphate which it is necessary to apply in order to produce different degrees of effect upon the fertility of soils.

It is desirable that these and other experiments should be tried at a number of stations in different parts of the country, in order that the needs of various crops may be considered and the effect of the fertilizers on different classes of soils ascertained.

The effect of a small amount of lime phosphate on the fertility of the soil is clearly great, but so far we do not know with accuracy the amount necessary to produce a given effect. The range in phosphoric acid contents in the soils of Kentucky, as determined from many hundred analyses, varies from 0.540 to 0.061.[1] In most cases the fitness of the

[1] See report of Dr. Robert Peter in Repts. Geol. Survey Kentucky, new series, vol. 5, 1878, N. S. Shaler, Director.

soil for grain tillage is measurably proportionate to the phosphatic contents. It seems almost certain, though not yet demonstrated, that the greater part of the phosphatic matter in the soil is in the state known as *insoluble*, and that it only becomes in small part, year by year, soluble, or, in other words, fitted for assimilation by plants. Whenever the soil contains the quantity of lime which characterizes the better class of Kentucky soils it is supposed that even if soluble phosphatic manures are applied the superphosphate becomes again insoluble by taking up a molecule of lime. It is therefore an interesting question as to the means by which the lime phosphate enters the plants. It may be that the solution is effected through the action of the various humic acids of the soil or it may arise from some specific change which takes place at the contact of the soil with the roots. It is evident that this point requires precise determination, for on it will depend further experiments as to the methods of applying phosphatic manures.

There is yet another point on which we need experiments. Many of our rock phosphates, especially those which are distinctly bedded, contain low percentages of phosphatic matter. Many of our lime phosphates contain crystals of apatite and calcite so intermingled that it is not possible to separate them; yet from these deposits it will be easy to produce a mixture of lime carbonate and lime phosphate containing from 10 to 20 per cent. of phosphoric acid. The value of such material for manure has never been determined. If it can be used in a way which will give to the fields the full value for both the lime and the phosphorus it will open a way for an extensive production of cheap fertilizers.

The foregoing considerations give the general results of the preliminary inquiry into phosphatic manures of which Dr. Penrose's work forms a part. Before we go further into these studies I much desire to have the criticism and advice of others who have considered this subject. It is with this view that I have ventured to give in the foregoing pages an account of the aim of the inquiries I have in hand. The questions are at once chemical and geological, and demand much co-operation for their solution. Much of the work of searching for the unknown phosphatic deposits of this country will necessarily have to be undertaken by local students of geology or by commercial explorers in search of such deposits. Unfortunately, the unfamiliar aspect of the various forms of phosphatic deposits will make this task under any circumstances difficult. There is no substance of equally wide diffusion among those of considerable commercial importance which, in the present state of popular knowledge, so readily escapes detection as lime phosphate. It may be hoped that the following memoir may make it easier for explorers to recognize this class of deposits.

My own as well as Dr. Penrose's acknowledgments are due to many persons who have given him aid in the prosecution of his work. To Prof. Charles U. Shepard, jr., of Charleston, S. C., Dr. Penrose is par-

ticularly indebted for much information and access to a great deal of valuable matter contained in his unpublished notes on American and foreign phosphatic deposits.

In justice to Harvard University it should be said that the following report, although designed as a memoir of the U. S. Geological Survey, was used in manuscript form by Dr. Penrose as his thesis for the degree of doctor of philosophy in that institution.

NATURE AND ORIGIN OF DEPOSITS OF PHOSPHATE OF LIME.

By R. A. F. Penrose, Jr.

IMPORTANCE OF PHOSPHATE OF LIME IN NATURE.

Phosphorus is one of the most universally distributed of all the elements. It is found in all animal and vegetable matter, as well as in most eruptive and sedimentary rocks. Phosphoric acid composes over 40 per cent. of the ashes of bones and in the vegetable kingdom it is especially abundant in the seeds of plants. Thus the ash of wheat contains over 49 per cent. of phosphoric acid.

It has been estimated that for each cow kept on a pasture through the summer there are carried off, in veal, butter and cheese, not less than fifty pounds of phosphate of lime. Consequently it will be seen that phosphoric acid is one of the most important elements of plant food, and no soil can be productive which is destitute of it. The necessity of restoring phosphoric acid to an exhausted soil has been acknowledged from very ancient times, though the cause of its stimulating effect was unknown until a comparatively late date. In the days of the Romans the excrements of birds, from pigeon-houses and bird-cages, brought a high price, and Edrisi relates that the Arabians, as early as 1154 A. D., used the guano deposits found along their coast for agricultural purposes. Garcilaso de la Vega (Comentarios Reales, lib. V, 1604) says that the Peruvians, in the twelfth century, used the guano beds on their islands as fertilizers. Of such importance did they esteem the material of these beds that the penalty of death was imposed by the early Incas on any one found killing the birds that made these precious deposits. It was not, however, until the early part of this century, when Liebig and others showed the important part played by phosphoric acid in vegetable life, that artificial phosphatic manures came into use, and it is only in the last twenty years that the mining of natural phosphates with their conversion into superphosphates has assumed its present great and steadily increasing importance.

CLASSIFICATION OF DEPOSITS OF PHOSPHATE OF LIME.

The classification of deposits of phosphate of lime is a matter attended with many difficulties, not only on account of the great variety of forms in which phosphate of lime occurs, but also because many varieties gradually blend into one another, thus often rendering it uncertain to which class a special deposit should be referred. The classification given below is based mainly on the chemical composition of the deposits. These are grouped under two principal headings, namely, *mineral phosphates* and *rock phosphates*.[1] The former includes all deposits of phosphate of lime which, besides having the other properties inherent in a true mineral, have a definite chemical composition or at least show a strong tendency toward such properties and composition. The latter includes those deposits which, having no definite chemical composition and lacking the homogeneous nature and other fixed characteristics of a true mineral, cannot be classed with mineral phosphates. These two classes are again subdivided as follows:

- Mineral phosphates:
  - Apatites.
    - Fluor-apatites.
    - Chlor-apatites.
  - Phosphorites.
- Rock phosphates.
  - Amorphous nodular phosphates.
    - Loose nodules.
    - Cemented nodules or conglomerates.
  - Phosphatic limestone beds.
  - Guanos.
    - Soluble guanos.
    - Leached guanos.
  - Bone beds.

The various phosphate deposits of North and South America, Europe, Africa, and other localities will be treated under the different divisions of the above classification, each deposit being described under the heading to which it belongs. Mineral phosphates will be taken up first, and then the various representatives of rock phosphates will be described. Special attention will be given to the phosphate deposits of the United States and Canada, which were visited and studied by the writer.

MINERAL PHOSPHATES.

APATITES.

Apatite is found in both stratified and crystalline rocks, but is much more plentiful in the latter, especially in metamorphic limestone, syenite, garnetiferous, hornblendic, and pyroxenic, gneiss, mica-schist, and igneous and volcanic rocks.

The mineral occurs in both the massive and the crystalline form. It belongs to the hexagonal system of crystallization, has a vitreous or subresinous luster, is translucent and sometimes transparent, has a hardness of 5, a specific gravity of 3.17 to 3.25, is brittle, of a white, yellow, green, or red color, gives off phosphorescent light when heated,

[1] It will be seen that the determination which phosphate shall be classed under minerals and which under rocks must in certain cases be somewhat arbitrary, but the classification is intended simply as a matter of convenience in describing the various deposits, and as such answers its purpose sufficiently well.

and becomes electric by application of heat or friction. It occurs principally in the early crystalline rocks and is found in New York, New Jersey, Maine, Canada, and other places in North America. In Europe it is found in England, France, Saxony, Tyrol, Bohemia, Spain, Norway, and many other regions. The only deposits of economic importance as yet discovered are in Canada, Norway, and Spain.

Prof. J. D. Dana gives as a formula of apatite $Ca_3O_8P_2+\frac{1}{3}(Cl_2F_2)$, in which the fluorine and the chlorine may replace each other in any proportion. When there is more fluorine than chlorine present the mineral is called fluor-apatite, and when less it is called chlor-apatite.[1] The apatites of Canada and of Spain, as well as most of those from Norway, are essentially fluor-apatites, though they almost always contain 0.01 to 0.5 of chlorine. Occasionally apatites are found free from chlorine, as some of those of Nassau and the Tyrol, but they are never found entirely free from fluorine. The apatite of Snarum, Norway, contains more chlorine than any other known apatite, amounting, as it does, to 2.71 per cent. of that element.[2] The apatite deposits of Canada, being at present more extensively worked than any others and consequently better known, will be described first; after them the apatites of Norway and Spain.

APATITES OF CANADA.

Phosphates were discovered in considerable quantities in Canada before the middle of this century, and were described by Dr. T. Sterry Hunt in the Canadian Geological Survey Reports for 1848. Shortly afterwards they were mined in the counties of Lanark and Leeds, Ontario. But the first regular mining operations of any considrable importance were begun in 1871, in the townships of Buckingham and Portland, Ottawa County, Quebec, where apatite had been discovered several years later than in Ontario. The first company to operate on a large scale here was known as the Buckingham Mining Company. It worked successfully until 1875, when a sudden fall in the prices of the phosphate market led to a stoppage. For several years after this the mines were worked by private parties, until, in the years 1881 to 1883, the large mining companies which now control the richest properties in Canada were organized. Many of the phosphate properties in Ontario have been worked by the so-called "contract system." Under this system the farmers of the neighborhood, whenever they are without employment, blast out a little phosphate. The result of such a method is, of course, that the whole of a property is soon cut up with small pits and trenches, rarely exceeding twenty feet in depth, and often interfering considerably with later and larger mining operations.

There are two principal districts in Canada where apatite occurs in considerable quantities. The first is in Ottawa County, Province of Que-

[1] J. D. Dana: Manual of Mineralogy and Lithology, 1885, p. 213.

[2] O. Ramon T. Muños de Luna: Estudios químicos sobre economía agricola en general, y particularmente sobre la importancia de los abonos fosfatados.

bec. It consists of a belt running from near the Ottawa River, on the south, for over sixty miles in a northerly direction, through Buckingham, Portland, Templeton, Wakefield, Denholm, Bowman, Hincks, and other townships. The belt probably stretches still farther to the north, but the country in that direction has been but little explored, and is scarcely known, except to trappers and Indians. The belt averages in width from fifteen to twenty-five miles.

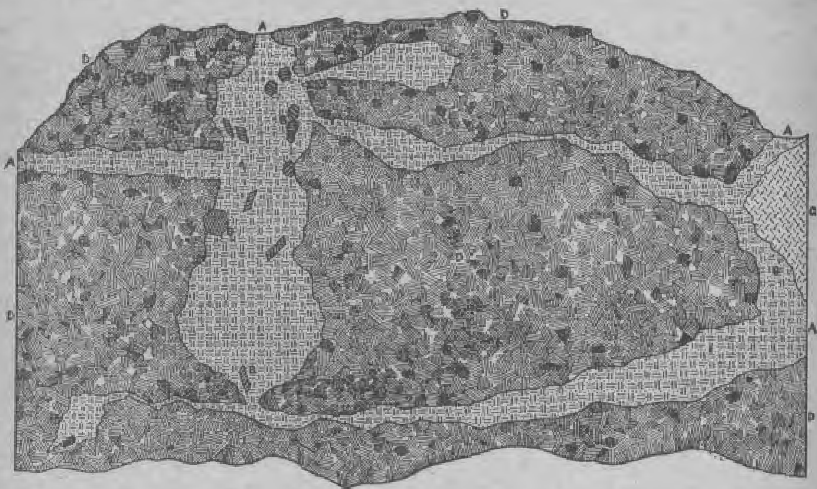


FIG. 2. Apatite in the Bonanza pit, Union mine, Portland, Ottawa County, Quebec, Canada. A, apatite; B, mica; C, white feldspar; D, pink and white feldspar, mica, and pyroxene. Scale: 1 inch = 16 feet.

The second phosphate district is in Ontario, principally in the counties of Leeds, Lanark, Frontenac, Addington, and Renfrew. This district is much larger than that of Quebec. But the apatite is much more scattered, and, though special deposits are in some places much more continuous than those of Quebec, the mineral has not yet been discovered in such large pockets as occur in the latter district. The belt which contains the deposits runs from about fifteen miles north of the St. Lawrence River in a northerly direction to the Ottawa River, a distance of about one hundred miles. It varies from fifty to seventy-five miles in breadth.

The above-mentioned districts are the regions where apatite has been found most plentifully, but it also occurs in other places, though, so far as has been discovered, in much smaller quantities.[1]

The apatite occurs in the upper part of the Lower Laurentian formation, the horizon being characterized by large quantities of pyroxene rock. The principal phosphate-bearing band consists of quartzites, gneisses, schists, feldspar, and pyroxenic and calcareous rocks, having an aggregate thickness, according to Vennor, of twenty-six hundred to

[1] Lately it has been found that apatite is very generally distributed in Pontiac County, Quebec.

thirty-nine hundred feet. All the beds are more or less completely metamorphosed, being sometimes indistinctly stratified and at other times massive and with no traces of bedding. The rocks, often contorted, all dip at a vertical or almost vertical angle. Sometimes the gneiss contains large quantities of mica and has a distinctly foliated structure. At other times it is impregnated with large quantities of pyroxene, as in the Quebec district. In the Ontario district this pyroxene is often replaced by hornblende of a dark-green, lustrous character. A highly garnetiferous gneiss is also often found in large quantities in some of the apatite localities. In the Quebec district there is a series of trap dikes running in a general east and west direction. By some they are supposed to be connected with the occurrence of the apatite. But the trap is, probably, of a later date than the apatite, as it is sometimes found passing through pockets of that mineral (Fig. 4).

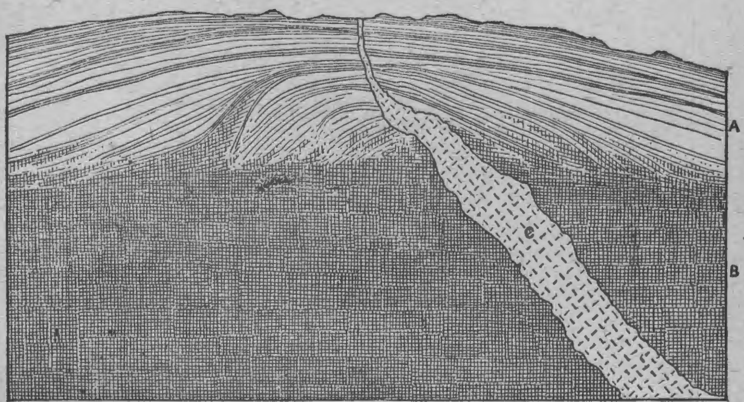


FIG. 3. Section on south side of hill on north side of Rheaump Lake, Templeton, Ottawa County, Quebec, Canada. A, stratified rock; B, pyroxene; C, feldspar. Scale: 1 inch = 16 feet.

The principal difference between the country rock of the Quebec district and that of the Ontario district is that the rocks in the latter region are often much more hornblendic than those in the former, and are often found in the form of a more or less hornblendic gneiss. The country in the Quebec apatite district is rough and mountainous. The hills are of a remarkably uniform height, rarely rising over five hundred to six hundred feet above the level of the neighboring Du Lièvre River. In Ontario, on the other hand, the land in Leeds, Lanark, Frontenac, and Addington Counties is low, and sometimes shows a smooth, glaciated surface, covered by a thin layer of soil. In Renfrew County, however, the land is more hilly, and resembles that of the Ottawa district. As before remarked, the apatite occurs, almost without exception, in association with pyroxenic or hornblendic rocks. This rule holds especially true in the Quebec district, where the phosphate has never yet been found without being associated with pyroxene rock, possibly often of vein origin. This, called pyroxenite by Prof. T. Sterry Hunt, occurs in ridges, running in a general northeast and southwest direction, following the general course of

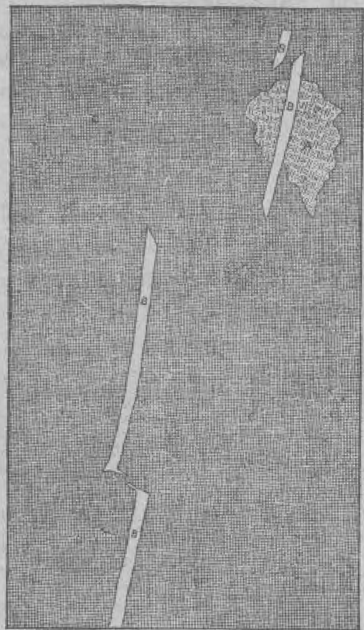


FIG. 4. Dike at Union mine, Portland West, Ottawa County, Quebec, Canada. A, apatite; B, trap; C, pyroxene.

the strike of the country gneisses. It forms, together with lilac-colored orthoclase, quartzite, and trap, the mass of many of the hills in the phosphate district, while the stratified and massive gneisses are often seen bordering the sides of the ridges, as shown in Fig. 5.

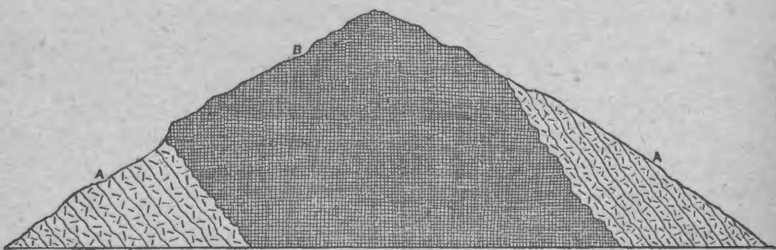


FIG. 5. Ideal section southeast and northwest through the Emerald mine hill, Buckingham, Ottawa County, Quebec, Canada. A, country quartzite, gneiss, etc.; B, pyroxene. Scale: 1 inch = 180 feet.

The pyroxene rock is never found distinctly bedded, though occasionally a series of parallel lines can be traced through it, which, while possibly the remains of stratification, are probably often joint planes. Sometimes, when the pyroxenite has been weathered, apparent signs of bedding are brought out, which are often parallel to the bedding of the country rock. Thus at Bob's Lake mine, in Frontenac County, a rich-green pyroxenite occurs which exhibits this structure. For 10 feet down from the surface this apparent bedding can be distinguished. It gradually grows fainter, until it disappears in the massive pyroxenite below. A similar phenomenon has been observed at the Emerald mine, Buckingham Township, Ottawa County, Quebec, and at several other places (Fig. 6). It can also be seen in the crystalline rocks on Newport Island, opposite Tiverton, R. I. There, for a depth of from one to two feet, an apparent stratification can be seen, and the rock below gradually becomes more massive, until it merges into the apparently homogeneous mass of the hill.

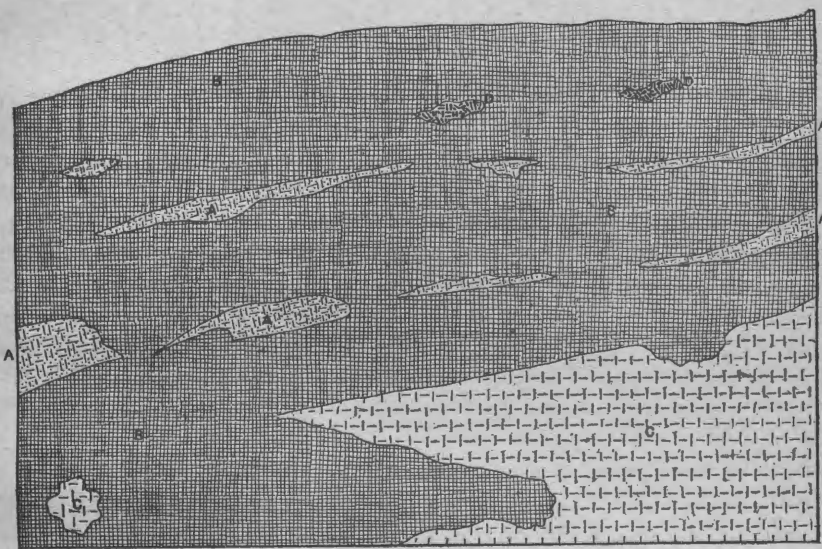


FIG. 6. Section in a pit near the Emerald mine (looking west), Buckingham, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene; C, feldspar; D, pyrite. Scale, 1 inch = 6 feet.

The pyroxene occurs in several different forms. Sometimes it is massive, of a light or dark green color, and opaque or translucent; at other times it is granular and easily crumbled. Occasionally it occurs in a distinctly crystalline form, the crystals being in color of different shades of a dull green, generally opaque or translucent, but sometimes, though rarely, almost transparent. The massive variety is the most common, and composes the greater part of the pyroxenites found in the phosphate districts.

The associated feldspar is generally a crystalline orthoclase, varying in color from white to pink and lilac; occasionally, as in Denholm and Bowman Townships, Ottawa County, Quebec, it occurs as a whitish-brown, finely crystalline rock. The trap is of the dark, almost black, variety. Thin sections under a microscope show it to have a very variable composition—a net-work of striated blades of triclinic feld-spar, brownish augite, black opaque grains of magnetite, and, commonly, small quantities of a green, chloritic mineral.[1] The quartzite is white, gray, or blue. The blue variety often contains specks of felsite. These pyroxenes, feldspars, and quartzites are often mixed up in a perfect net-work, very similar to that seen at Marblehead, Mass., and at

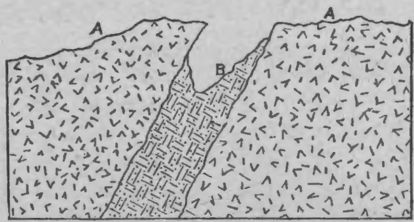


FIG. 7. Section of apatite vein near Smith's mine, Oso, Frontenac County, Ontario, Canada. A, country syenite; B, red and green apatite. Scale: 1 inch = 8 feet.

many places in the metamorphic rocks of Mount Desert Island. Often whole hills are formed of these rocks, mixed in various proportions (Figs. 8 and 9). The gneiss in some places has no distinct line of separation from the pyroxene, but seems to have been impregnated with some of it, forming for a few feet from the line of contact a more or less pyroxenic gneiss, which is easily decayed and eroded by weathering (see Fig. 3).

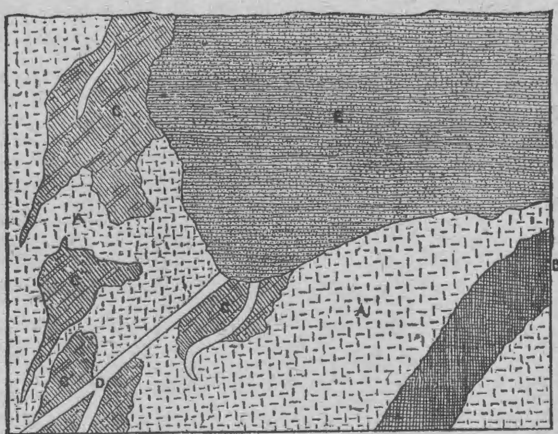


FIG. 8. Horizontal view of surface rock at Turner's Island, Clear Lake, Canada. A, feldspar; B, pyroxenite; C, hornblende; D, feldspar dykes; E, soil. Scale: 1 inch = 6 feet.

In the Ontario district, as mentioned before, the pyroxene is often replaced by hornblende. Thus at Bell's mine, in Frontenac County, little or no pyroxene is met with, and in its place large quantities of dark green hornblende occur. The apatite here is found in a rock consisting

[1] B. J. Harrington: Geol. Survey Canada, Rept. Progress, 1877–'78.

of green hornblende and white feldspar, which forms a ridge about one hundred yards wide parallel to the strike of the country gneiss. To complete the list of rocks found in the apatite districts it is necessary to mention the large veins of crystalline calcite, which often contain serpentine and chrysotile. In the occurrence of these veins this Canadian apatite region is in marked contrast with that of Norway, where little calcareous matter is found.

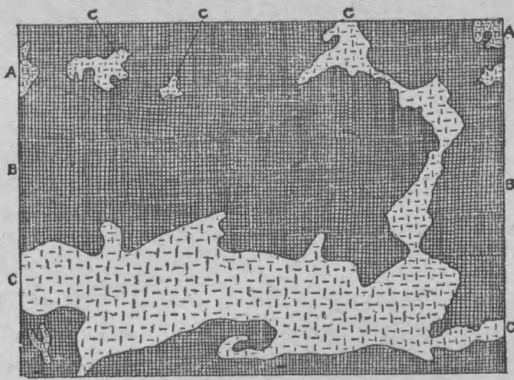


FIG. 9. Pyroxene surface, Star Hill, Union mine, Portland, East Ottawa County, Quebec, Canada. A, apatite; B, pyroxene; C, feldspar. Scale: 1 inch = 8 feet.

The apatite of Canada is found occurring in a great variety of ways. Prof. T. Sterry Hunt regards most of the workable deposits as veins, but he thinks there are also some deposits which occur in beds. He has discovered small masses of apatite marking the lines of stratification in

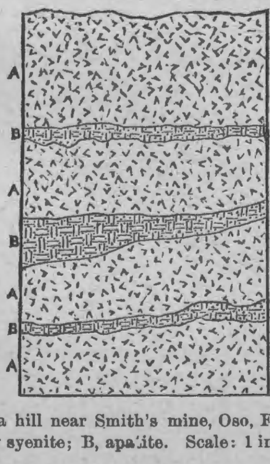


FIG. 10. Opening in west side of a hill near Smith's mine, Oso, Frontenac County, Ontario, Canada. A, country syenite; B, apatite. Scale: 1 inch = 24 feet.

the pyroxene.[1] An instance of this was seen by the writer in an old pit in Buckingham Township, Ottawa County, Quebec, where the apparent lines of stratification were marked by bands of apatite (see Fig. 6).

[1] Geol. Survey Canada, Rept. Progress for 1863.

Professor Hunt thinks that most of the deposits of apatite are concretionary vein stones and have resulted from a hot-water solution. He bases his belief upon several characteristic facts concerning Canada apatite, such as the rounded form of many of the apatite crystals, which

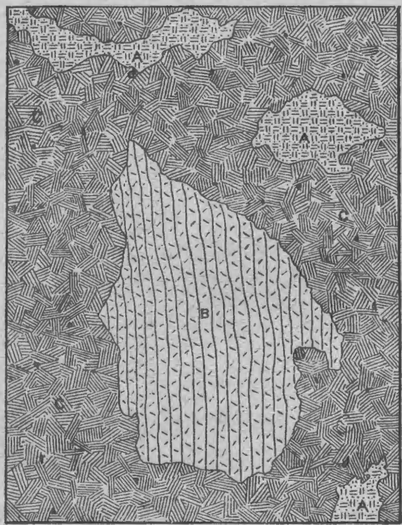


FIG. 11. Bowlder of country-rock embedded in pyroxene etc., High Rock mine, Portland West, Ottawa County, Quebec, Canada. A, apatite; B, country gneiss; C, mica, pyroxene, and feldspar. Scale: 1 inch = 6 feet.

he regards as due to the action of partial solution after deposition, and not of fusion, as suggested by Dr. Emmons.[1] Another argument is that one mineral in the vein is often found incrusting or containing frag-

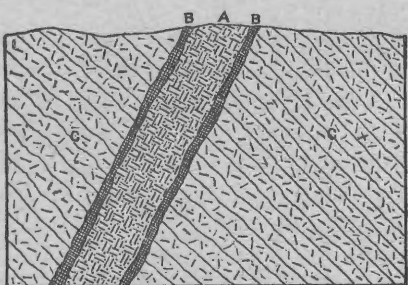


FIG. 12. Section of one of the northwest and southeast veins at Foxton's mine, Loughboro', Frontenac County, Ontario, Canada. A, apatite; B, pyroxene; C, country gneiss. Scale: 1 inch = 7 feet.

ments of another. Thus it is very common to find masses of crystalline calcite rounded into pebbles and buried in the centers of apatite crystals, which are themselves worn and rounded, showing, as Dr. Hunt

[1] Nat. Hist. New York, pt. 4, Geology, 1843, pp. 57, 58. Some of the dike stones of eastern Massachusetts, especially those in the town of Somerville, contain phosphate crystals which are similarly rounded.—N. S. S.

thinks, that the erosive action in the veins has taken place in at least two different epochs. The appearance in the veins of drusy cavities and the parallel deposition of the different minerals observed in many veins are also arguments for the theory of concretionary structure. Professor Dawson thinks that many of the deposits of the Ontario district are true beds.[1]

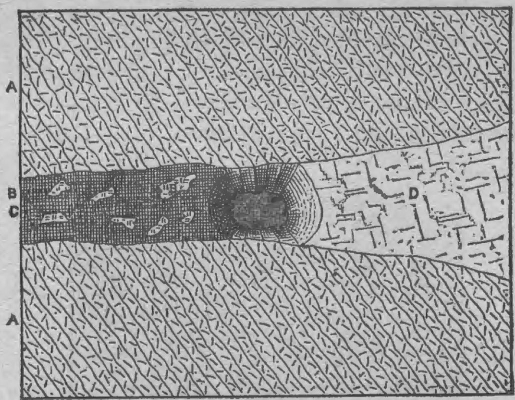


FIG. 13. Horizontal section showing natural cavity in vein, Loughboro', Frontenac County, Ontario, Canada. A, country gneiss; B, apatite; C, pyroxene; D, calcite. Scale: 1 inch = 7 feet.

Prof. B. J. Harrington[2] thinks that most of the phosphate deposits will come under the heading of fissure veins and pockets. He shows that many of the deposits cannot be beds, because they cut across the strata of the country rock.

Many of the veins are of considerable length. A very continuous vein, composed of hornblende, calcite, and apatite, mixed in varying proportions and associated with sphene, zircon, mica, scapolite, etc., is found in Renfrew County, Ontario. This vein, or what may be a series of similar and parallel veins, was traced by the writer for a distance of three miles, and it is said by the native prospectors to be traceable for 27 miles. It runs in a N. 40° E. direction, widening and contracting at intervals and varying from three to thirty feet in thickness. It can best be examined on Turner's Island, in Clear Lake, Renfrew County, Ontario, where several small openings have been made in it for the purpose of mining the rich apatite found there.[3] The island is three-quarters of a mile long and from one hundred feet to a quarter of a mile wide. The vein runs through its longer axis from one end to the other. The apatite occurs in crystals, sometimes in considerable quantities and composing the greater part of the vein matter and at other times

[1] Quart. Jour. Geol. Soc. London, vol. 32, 1876, p. 289.

[2] Geol. Survey Canada, Rept. Progress for 1877–'78–'79.

[3] The same or a similar vein is seen to great advantage on the land of Xavier Plaunt, on the south side of Clear Lake. It widens and contracts at intervals and runs in the same general direction as the Turner's Island vein.

scattered sparingly through a mass of the crystalline minerals which accompany it. Apatite crystals of immense size have been found here. One prism is said to have weighed seven hundred pounds; a crystal of zircon, almost a foot in diameter, is also said to have been found in the same vein. A crystal of sphene from this locality in the Harvard Mineral Cabinet measures over a foot in length. The country rock on the island consists of a confused mass of feldspar, coarse-grained, unstratified gneiss, and of a rock composed of feldspar and hornblende. Small quantities of green pyroxene are also found (see Fig. 8). The vein is said to change into pure calcite at its extremities. It shows no signs, as far as seen, of banded or concretionary structure, but consists of a mass of crystallized minerals mixed in an apparently indiscriminate manner.

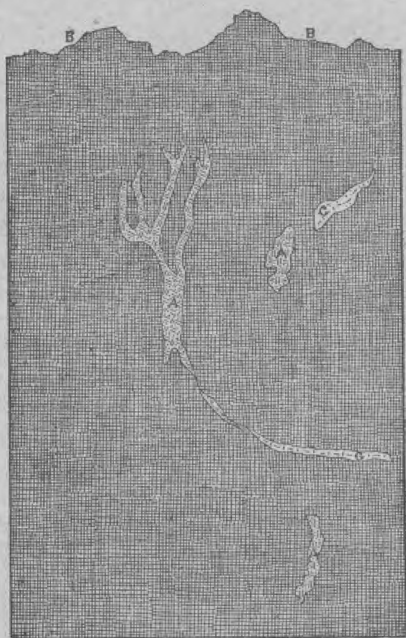


FIG. 14. Northeast side of a pit in the North Star mine, Portland East, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene; C, feldspar. Scale: 1 inch = 10 feet.

Like most apatite deposits in Canada, the vein has no sharp line of division from the country rock, but gradually blends into it. The hornblende in the country rock becomes more perfectly crystalline and occurs in larger masses as the vein is approached, until finally, when the vein is met, the hornblende and the feldspar crystallize out separately among the other minerals. "Such a blending of a vein with the walls," says Professor Dana, "is a natural result when its formation in a fissure takes place at a high temperature during the metamorphism or crystallization of the containing rock."[1] This blending of the country rock with the vein matter does not, however, always happen, as sev-

[1] Dana's Manual of Geology, 1875, p. 733.

eral cases were found where the apatite and associated minerals came into direct and sharp contact with the country rock (see Figs. 7 and 20). Thus, on the land of the Sly brothers, in Oso, Frontenac County, Ontario, there is a vein two feet wide in a gneissic rock. The boundary lines of the vein are sharply defined and white, red, and transparent calcite is associated with grass-green hornblende and brown apatite, in a mass apparently devoid of any banded structure (see Fig. 7). The vein dips at an angle of 85° N. and strikes E. and W. The country rock strikes N. 20° E. and dips 40° to 45° ESE. A somewhat similar instance is seen in the same township at Boyd Smith's mine. Here were three veins apparently occupying joint planes, and parallel to one another (see Fig. 10). The veins are composed principally of apatite and hornblende, and their general character is very similar to that of the last vein described. They strike N. 15° W. and dip at 10° NE. The strike of the country gneiss is N. 35° E., dip 60° SE., so that it is evident that the deposits cannot be beds. They can be traced for 50 yards along the side of the hill.

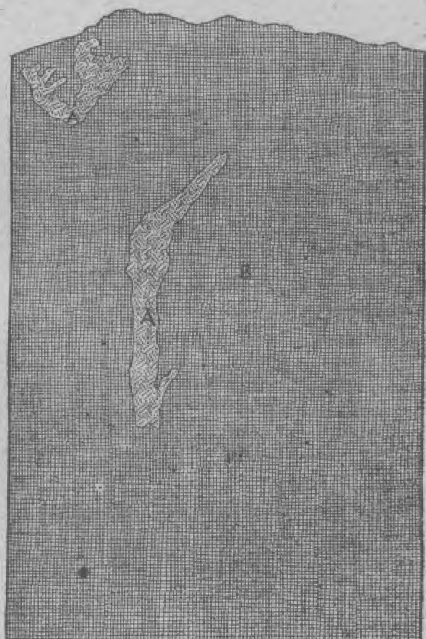


FIG. 15. Southwest side of a pit at North Star mine, Portland East, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene. Scale: 1 inch = 10 feet.

Some of the veins of apatite show a distinctly banded structure. On the land of James Foxton, in Frontenac County, township of Loughboro', there is a series of gash-veins running in a general northwest and southeast direction. They are of all sizes, from small ones not two inches thick to large ones three to six feet wide. The general character of all of them is the same. They occur in the country gneiss and occupy an almost vertical position. Fig. 12 shows a section of one of them, and most of the others are like it. It will be seen that the pyroxene lines both sides of the vein and the apatite comes in the middle. The strike and the width of nine of these veins were found to be:

N. 11° W., six inches wide. Red apatite.
N. 10° W., eighteen inches wide. Red apatite.
N. 8° W., one to three feet wide. Red apatite.
N. 20° W., one foot wide. Red apatite.
N. 8° W., one foot wide. Red apatite.
N. 35° W., six inches to one foot wide. Red apatite.
N. 36° W., one foot wide. Red apatite.
N. 45° W., one foot wide. Red apatite.
N. 30° W., one foot wide. Red apatite.

The country gneiss is much contorted and strikes in various directions. It has an almost vertical dip. On the same properties there are also other veins running in various directions, but they are generally of small extent. In one place a vein was seen composed on one side of a band of apatite and on the other of a band of pyrites of iron containing masses of talc.

FIG. 16. Southeast side of a pit at North Star mine, Portland East, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene; C, feldspar; D, mica. Scale: 1 inch = 10 feet.

Another instance of a banded vein occurs at Mud Lake, Templeton Township, Ottawa County, Quebec, where apatite, mica, and pyroxene form the contents of the vein.[1] But it is generally in the Ontario district that the banded structure is most often seen.

In the township of North Burgess, Lanark County, Ontario, are many examples of phosphate-bearing veins, some of which can be traced for

[1] B. J Harrington: Geol. Survey Canada, Rept. Progress for 1877-'78-'79.

over half a mile, while others are short and amount to little more than pockets. In places the ground is literally cut up by a net-work of these veins, varying from a few inches to over ten feet wide. Occasionally they

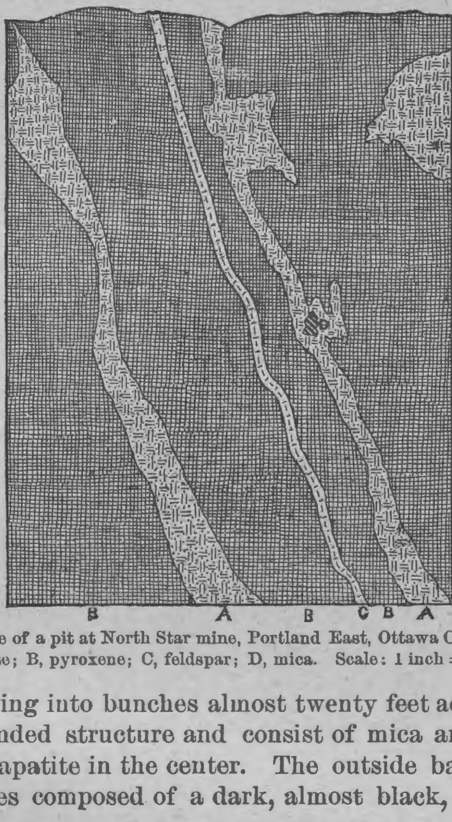


FIG. 17. Northwest side of a pit at North Star mine, Portland East, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene; C, feldspar; D, mica. Scale: 1 inch = 10 feet.

are found widening into bunches almost twenty feet across. The veins often show a banded structure and consist of mica and pyroxenite on the outside and apatite in the center. The outside bands of the veins are in some cases composed of a dark, almost black, talcose material.

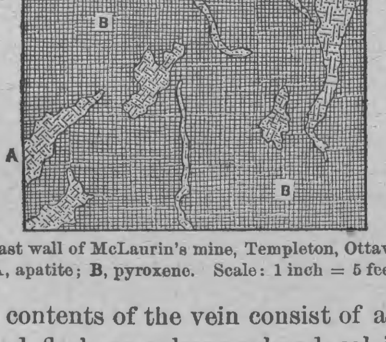


FIG. 18. Part of the northeast wall of McLaurin's mine, Templeton, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene. Scale: 1 inch = 5 feet.

In other places the contents of the vein consist of apatite, mica, pyroxenite, and white and flesh or salmon colored calcite, indiscriminately mixed and associated with small quantities of scapolite, zircon, sphene, talc, hornblende, specular iron ore, zeolites, and other minerals. Veins also occur which are almost entirely composed of apatite crystals scattered in a matrix of granular quartzite.

On the land of the Anglo-Canadian Phosphate Company, at Otty Lake, North Burgess, where some of these veins have been opened to a depth of seventy to eighty feet, the mode of occurrence of the apatite is well seen. The prevailing country rock here is quartzite and garnetiferous gneiss. In some cases the line of division between the vein matter and the country rock is sharply drawn, while in others they gradually blend. Both of these phenomena, as well as the banded and the unbanded structure, are often seen in different parts of the same vein. The apatite occurs in bunches, sometimes connected by seams of the same mineral. From a single one of these bunches over a thousand tons have been taken.

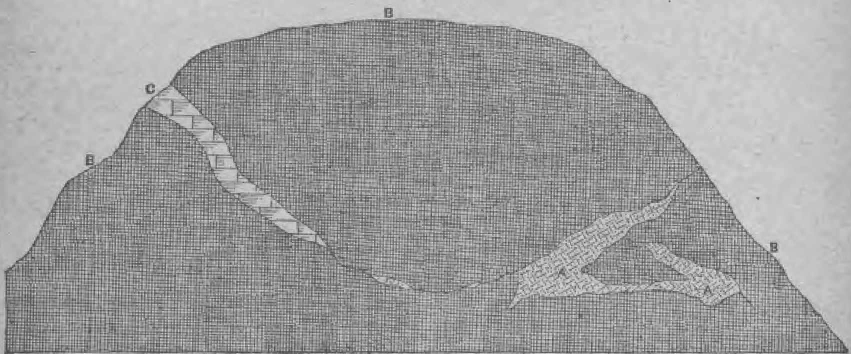


FIG. 19. Section at McKenzie's opening, looking ENE., Bowman, Ottawa County, Quebec, Canada. A, apatite, with pyroxene crystals; B, pyroxene; C, limestone. Scale: 1 inch = 50 feet.

The contents of the phosphate-bearing veins are often very variable at different points in the same vein, sometimes consisting mostly of apatite, scapolite, feldspar, and pyroxene, and at others being composed of crystalline limestone bearing crystals of the above minerals. Such a formation is seen on Henry Barr's land, in Renfrew County. At the McKenzie mine, in Bowman Township, Ottawa County, Quebec, there is a vein in a hill of lilac-colored feldspar and pyroxenite. One part of the vein is composed of massive apatite, holding crystals of pyroxene and scapolite, while another about fifty feet distant assumes a totally different character, being composed of a pink, crystalline calcite, bearing crystals of apatite. In some places the calcite has been worn away by the infiltration of water, and then the structure of the vein can be seen. The cavity is lined with crystals of scapolite and pyroxene, which come next to the country rock, while the calcite, bearing the crystals of apatite, comes in the middle (Fig. 19). This formation of drusy cavities in limestone leads is very common, especially in the Ontario district. Often the calcareous matter has been washed away, and crystals of apatite and their fragments are scattered over the bottom of the hollow. The formation of cavities seems especially apt to take place at the point of junction of the limestone and a harder mineral in the vein. Thus in the township of Loughboro', Frontenac County, Ontario, was seen the cavity represented in Fig. 13, where a mass of limestone in a vein came in contact with a mass of apatite-bearing pyroxenite. From this opening several hundred pounds of loose apatite crystals were taken. Though it will thus be seen that the apatite of Canada often occurs in well defined veins, yet the largest deposits yet discovered occur in irregular masses in the pyroxenic and feldspathic rocks (see Figs. 2, 14, 15, 16, 17, 18, and 21). They seem to occur at some places in fissures and at others as simple segregations. As a general rule it may be said that the vein character is best developed in the Ontario district, while the segregation and pocket formations are more common in the Quebec district. A very characteristic section, showing the occurrence of pockets of apatite is given in Fig. 18. It is a figure from the side of McLaurin's mine in Templeton, Ottawa County, Quebec. The mineral seems to lie in no definite vein, but to have been formed by the segregation of apatite from the including rocks. This seems especially probable, as the surrounding pyroxene often contains 10 to 15 per cent. of apatite and seems to increase in richness as the pocket is approached. It is also well known that phosphate of lime has, more than any other mineral, the property of forming into concretionary and segregated masses. Thus Professor Rogers found, in the materials dredged in the Challenger expedition, numerous phosphatic concretions scattered over many parts of the sea bottoms. Again, in the phosphorite deposits of southwestern France and of Estremadura, in Spain, the concretionary form is one of the most common conditions of the phosphate, while in the phosphate region of South Carolina the nodular phosphates, especially those from Bull River, show sometimes a distinctly concretionary structure. At Crown Point, N. Y., phosphate of lime occurs in radiating and botryoidal masses forming the eupyrchroite of Emmons, and even in the guano beds of Peru concretionary nodules of phosphate of lime have been found.[1]

The pockets and fissures of apatite are of variable size (see Figs. 2, 14, 15, 16, 17, 18, and 21), sometimes being only a fraction of an inch in diameter and sometimes consisting of immense bodies of massive or crystalline apatite, measuring many feet in thickness. Such pockets are to be seen at the Emerald, Battle Lake, North Star, High Rock, Union, and other mines on the Du Lièvre River. The apatite is, generally, not sharply divided from the pyroxenite, but gradually blends with it. The pockets show sometimes a banded structure, such as that of a cavity lined with pyroxene and the central part occupied by apatite. Occasional large bowlders of country rock are found embedded in the

[1] In the introduction to this report yet other instances of concretionary forms are noted, as well as the fact that many are probably at present forming in the muds beneath certain swamps.—N. S. S.

apatite (see Fig. 12). Nearly all these pockets and fissure veins seem to take their distinctive characters from the including rocks. Thus where the including rock is pyroxenic, feldspathic, and calcareous, the crystals associated with the apatite are generally pyroxene, feldspar, and calcite; and where the country rock contains large amounts of hornblende, as at Bell's mine, Storrington, Frontenac County, at Barr's mine, and on Turner's Island in Clear Lake, in Renfrew County, Ontario, there are always found large quantities of this mineral in the vein matter. The few veins, however, in which the lines of separation from the country rock are sharply drawn, do not seem to be so dependent on the including rocks for their component minerals.

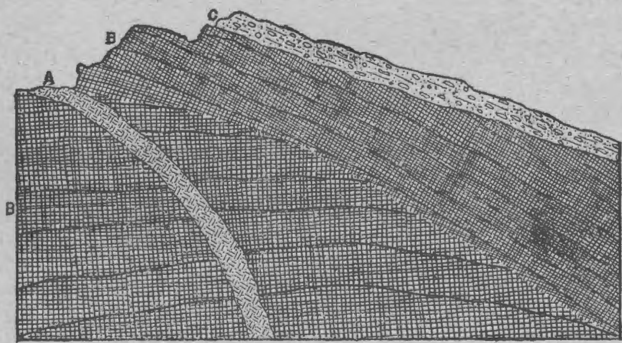


FIG. 20. Section in a pit near the Emerald mine, Buckingham, Ottawa County, Quebec, Canada. A, apatite; B, schistose pyroxene; C, drift. Scale: 1 inch = 6 feet.

The depth to which the apatite extends is probably, for all practical purposes, unlimited. Some bunches of the mineral run out, but others are found at a greater or less distance below. The deepest openings in Canada are the North Star mine, township of Portland, county of Ottawa, Quebec, and the Battle Lake mine, township of Templeton, of the same county. In September, 1886, they had reached the depths, respectively, of 350 feet and 210 feet. In both shafts large bunches of apatite were found, separated by pyroxenic or micaceous rocks containing smaller seams and bunches of that mineral.

The apatite of Canada varies considerably in its physical character. Its color is green, red, brown, white, blue, purple, or black. The black color is generally caused by the decomposition of the associated iron pyrites and is seen in Ottawa and Frontenac Counties. Apatite occurs in the crystalline, subcrystalline, massive, or granular form. The granular variety, known as "sugar apatite," is of a white or pale-green color and looks like coarse sand, more or less coherent. It occurs principally at the Little Rapids mine, township of Portland, and McLaurin's mines, township of Templeton, Ottawa County, Quebec, and is one of the purest forms of apatite mined. It is uncertain what could have caused the apatite to assume this granular condition. Some shipments from Ottawa County have analyzed 88 per cent. of tribasic phosphate of lime. The apatite varies very much in its ability to withstand weathering. When it is free from pyrites it endures it very well and is almost as resistant to corrosion as quartz; but when pyrite is present it quickly crumbles away. In some places where pyrites of iron and copper are found the apatite is brown and rusty for a depth of several feet.

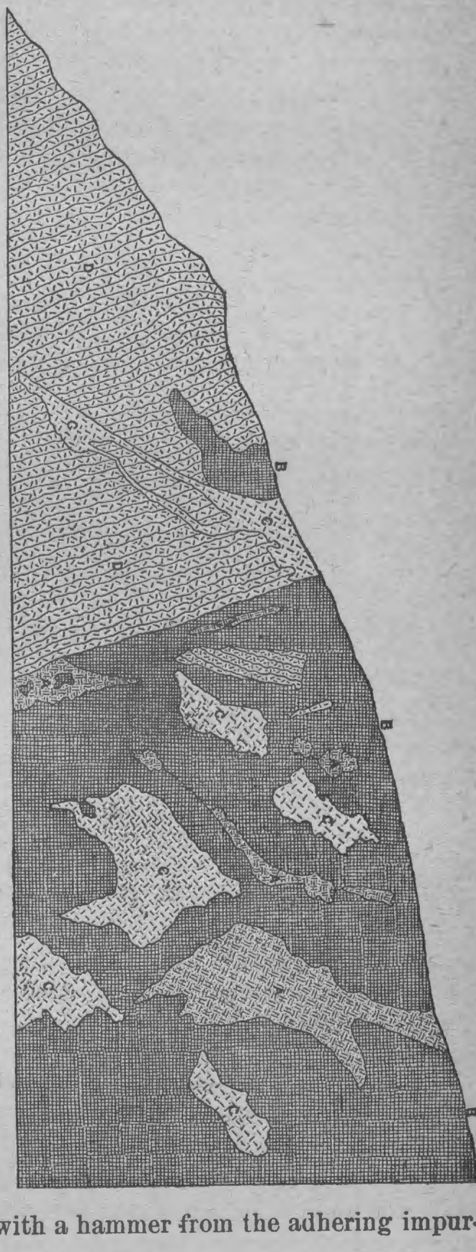


Fig. 21. North side of cut in west side of North Star hill, Portland East, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene; C, feldspar; D, country gneiss, quartzite, and felsite. Scale: 1 inch = 25 feet.

Below is given a list of some of the more important minerals of the Canada apatite districts. The crystals often occur of immense size and in a state of great perfection. The zircons, sphenes, scapolites, pyroxenes, apatites, and micas are especially fine, and probably are found nowhere else in such quantities and in such perfection:

Apatite.	Opal.
Calcite.	Chalcedony.
Fluor-spar.	Albite.
Pyroxene.	Scapolite.
Hornblende.	Wilsonite.
Phlogopite.	Talc (steatite).
Garnet.	Chlorite.
Epidote.	Prehnite.
Idocrase.	Chabasite.
Tourmaline.	Galena.
Titanite.	Sphalerite.
Zircon.	Molybdenite.
Orthoclase.	Graphite.
Quartz.	

The apatite, after being blasted out, is put through the process of "cobbing," which consists in breaking it with a hammer from the adhering impurities.

The highest grade which is shipped rarely averages over 85 per cent. tribasic phosphate of lime, and none of the mines ship much phosphate which does not average at least 70 per cent. Eighty per cent. apatite is considered first quality and sells for 11 to 12 pence a unit.[1] The principal market for the Canada apatite is Europe. Great Britain and Germany consume over three-fourths of the total product, which, in 1885, amounted to 23,908 tons. The market is unlimited and the output is yearly increasing, so that phosphate mining bids fair, in a few years, to be one of the most important industries of Canada. The annexed tables will show the output of the mines in past years, as well as the present markets.

According to the Canadian Mining Review, January, 1886, the product for the past five years has been:

	Tons.
1881	15,601
1882	17,181
1883	17,840
1884	22,143
1885	23,908
Total for five years	96.673

Shipments to different ports (same authority):

	Tons, 1884.	Tons, 1885.
Liverpool	8,557	9,563
London	4,389	7,683
Hamburg	2,970	3,524
Bristol	1,824	2,056
Glasgow	3,083	482
Barrow	......	350
Penarth Roads	100	100
Cardiff	......	65
Sharpness	......	45
Hull	......	40
Dublin	210	......
Sunderland	60	......
Bristol Channel	50	......
United States	200	......
Consumed in Canada	700	......
Total	22,143	23,908
From Ontario district, 1885		1,500
From Quebec district, 1885		22,408

The origin or chemical history of these Laurentian phosphates has been a matter of considerable dispute. Dr. T. S. Hunt says that phosphates, like silica and iron oxide, were doubtless constituents of the primitive earth's crust, and that the production of apatite crystals in granite veins or in crystalline schists is a process as independent

[1] The expression 11 to 12 pence a unit is the commercial method of signifying the value of the apatite. It means 11 to 12 pence for each per cent. Thus 80 per cent. phosphate at 11 to 12 pence per unit would be worth $17.60 to $19.20 per ton

of life as the formation of crystals of quartz or of hematite.[1] Prof J. W. Dawson,[2] on the other hand, thinks the Canada apatites are of animal origin, and bases his belief on the presence of eozoön and of graphite in the associated beds and of the fluoride of lime in the apatite. He says: "The probability of the animal origin of the Laurentian apatite is, perhaps, further strengthened by the prevalence of animals with phosphatic crusts and skeletons in the primordial age, giving a presumption that, in the still earlier Laurentian, a similar preference for phosphatic matter may have existed, and, perhaps, may have extended to still lower forms of life, just as, in more modern times, the appropriation of phosphate of lime by the higher animals, for their bones, seems to have been accompanied by a diminution of its use in animals of lower grade."[3] Messrs. Brögger and Reusch,[4] in their description of the Norwegian apatites, think that they are of purely eruptive origin.

[1] Chem. and Geol. Essays, 1875, p. 311.

[2] Quart. Jour. Geol. Soc. London, vol. 32, 1876, p. 290.

[3] The reader should note the fact that since the admirable researches of Möbius it is doubtful whether eozoön be of organic origin.—N. S. S.

[4] Zeitschr. Deutsch. geol. Gesell., Berlin, vol. 27, 1875.

Table giving analyses of apatites of Canada by Christian Hoffman, Geological Survey of Canada. 1877–'78.

[I is from Storrington, province of Ontario ; II is from Buckingham, province of Quebec ; III is from North Burgess, province of Ontario ; IV is from Portland, province of Quebec; V is from Loughboro', province of Ontario : VI is from Portland, province of Quebec ; VII is from Buckingham, province of Quebec ; VIII is from Templeton, province of Quebec.]

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Phosphoric acid (1)	40.373	41.080	39.046	41.139	40.868	40.518	34.032	40.812
Fluorine (2)	3.311	3.474	3.791	3.863	3.731	3.377	2.855	3.554
Chlorine (3)	0.438	0.260	0.476	0.229	0.428	0.086	0.101	0.040
Carbonic acid (4)	0.026	0.370	0.096	0.223	0.105	0.855	2.848	0.518
Lime	47.828	49.161	46.327	49.335	48.475	49.041	44.198	49.102
Sulphur (5)	....	....	....	....	....	....	3.507	....
Calcium	3.732	3.803	4.258	4.195	4.168	3.603	3.062	3.763
Magnesia	0.151	0.158	0.548	0.180	0.158	0.205	0.422	0.620
Alumina	0.609	0.705	1.190	0.566	0.835	0.267	1.979	0.565
Nickel, cobalt, and copper	....	....	....	....	....	....	Not det.	....
Iron	....	....	....	....	....	....	5.370	....
Sesquioxide of iron	0.151	0.125	1.290	0.094	0.905	0.083	0.120	0.125
Alkalis	?	?	?	?	?	?	?	?
Insoluble residue	3.890	0.370	3.490	0.060	1.150	1.630	2.050	0.630
Total	100.509	99.506	100.512	99.884	100.823	99.665	100.544	99.729
(1) Equal to tribasic phosphate of lime	88.138	89.682	85.241	89.810	89.219	88.455	74.295	89.098
(2) Equal to fluoride of calcium	6.796	7.131	7.781	7.929	7.658	6.932	5.860	7.295
(3) Equal to chloride of calcium	0.685	0.406	0.744	0.358	0.669	0.134	0.158	0.062
(4) Equal to carbonate of lime	0.059	0.840	0.218	0.507	0.239	1.943	6.473	1.177
(5) Equal to pyrrhotite	....	....	....	....	....	....	8.877	....

Analysis of apatite of Canada, by Dr. C. U. Shepard, jr.

	IX.
Phosphoric acid	39.80
(Equal to bone phosphate, 86.88.)	
Sand	5.91

APATITES OF NORWAY.

Under the heading of apatites com e the phosphate deposits of Norway. They are found on the southern coast, and extend from Langesund Fjord to Arendal. They are also found scatteringly in Kongsberg, in the parish of Snarum. Most of them are fluor-apatites, though they all contain some chlorine, and the apatite from Snarum contains 2.71 per cent. of this element.[1] The apatite occurs in both the crystalline and the massive form, and varies from white and yellow to green

[1] A dark-blue or greenish-blue variety of crystalline apatite is found at Arendal, and is known as moropite.

or red. Some of it is the richest phosphate at present mined, averaging at times over 90 per cent. of phosphate of lime.[1] (See analyses, p. 45).

The mineral occurs in veins in the country gneisses, granites, quartzites, and schists, and also in a rock called by Brögger and Reusch spotted gabbro (gefleckter Gabbro), which is composed of brown hornblende and white or gray labradorite. It is generally supposed to be of eruptive origin. From its description it is very similar to the rock, including the apatite, at Bell's mine, Storrington, Ontario, described above, which is composed of green hornblendes and white feldspar, and occurs as an apparently eruptive mass in the country gneiss. The apatite seems to occur indifferently in this hornblende rock and in the other country rocks, though, wherever it has been discovered in the latter, the spotted gabbro is generally found in the neighborhood. The apatite is associated most commonly with micas, enstatite, hornblende, pyroxene, albite, tourmaline, copper and iron pyrites, and other minerals, including many other species of rarer occurrence which are hereafter enumerated. As in the Canadian deposits, the contents of the veins are variable, being in some places composed almost entirely of either mica or enstatite, or both, and in others consisting of apatite with only a few micaceous and pyroxenic impurities. The veins are markedly different from the Canada veins in the fact that they contain only very little carbonate of lime. The large calcareous veins containing apatite, which are so common in the Canadian apatite districts, are never found in the apatite districts of Norway. The apatite veins in Norway are often very numerous and run in all directions, forming a perfect network all through the rock. Thus at Oedegården there is an area of 58 square rods which is cut up by innumerable veins of all sizes. The principal one of these has been worked to a considerable extent; it dips at 45°, has a thickness of one foot to four feet, and a length of about five hundred yards. Dr. C. U. Shepard, jr., who visited it in 1874, says: "It was found in the face of a low, rocky ledge, occurring in mica and a clay slate."[2] The veins often show a banded structure, having the mica and hornblende on the outside and the apatite in the center, though in other places they also show, as is generally the case in Canada, a confused mass of crystallized minerals. At Regårdsheien there are five parallel veins, one of them one and a half feet thick and one hundred to one hundred and fifty feet long; four dip at 30°, while the fifth is almost vertical (Brögger and Reusch). At Krageröe there is a large vein seven feet wide. It occurs in granitoid and schist rocks, though from the summit of the hill, from which it crops out, there protrudes the eruptive gabbro. The vein matter is com-

[1] Some of the phosphate deposits of Norway, especially at Krageröe, partake very much of the nature of phosphorites, but they are all classed together here, as both varieties are so intimately associated that they cannot be conveniently separated.

[2] Dr. C. U. Shepard, jr., MS.

posed largely of hornblende and apatite in varying proportions, with crystals of rutile occasionally scattered through the mass. The hornblende often contains cavities lined with crystals of the same substance, and of quartz, apatite, and other minerals. At Nestesvåg the apatite vein occurs in quartzite. The minerals found in the Norway apatite are:[1]

Quartz.
Apatite.
Calcite.
Talc.
Orthoclase.
Albite.
Oligoclase (and albite).
Esmarkite (anorthite ?).
Scapolite (and paleo-albite).
Tourmaline.
Hornblende.
Pyroxene.
Enstatite.
Phlogopite and green magnesian mica.
Chlorite.
Aspasiolite.
Titanite.
Hematite.
Rutile.
Menaccanite.
Magnetite.
Copper pyrite.
Magnetic pyrite.
Iron pyrite.

The apatite of Norway was mined as early as 1854. The first deposits worked were those of Krageröe, from which, between the years 1854 and 1858, 13,000 tons were taken and sold for $110,000. The Oedegården deposits were discovered in 1874 by Axel Esmark, a Norwegian mineralogist. They have since been worked on a small scale. The difficulty of mining Norwegian apatite has been so great, however, that the yearly output has never exceeded a few thousand tons, and the mineral at present has been almost driven out of the market by the Canada, Curaçoa, and other high-grade phosphates.

As regards the origin of the Norwegian apatites, Brögger and Reusch think they are of eruptive origin. The banded structure of the veins they ascribe to the way the minerals solidified from a state of fusion. The country rocks are almost absolutely destitute of phosphoric acid in any form, and, consequently, they infer that the vein matter is in no way dependent on the surrounding rocks. Another argument which they bring up in support of the eruptive theory is that veins are often seen to be fine-grained on the outside and coarse and crystalline in the center.

Table giving analyses of apatite of Norway, by Dehern.

	Yellowish brown.	Brown.	Black.	General sample.	Poor quality.
Phosphoric acid	34.82	33.25	26.25	34.88	17.56
Equivalent to bone phosphate	76.01	72.58	57.30	76.14	38.33
Sand	7.07	7.81	21.01	4.95	35.89

[1] Zeitschr. Deutsch. geol. Gesell., vol. 27, 1875, pp. 672, 673.

Table giving analyses of high-grade Norwegian apatite, by Dr. C. U. Shepard, jr.

	I.	II.
Phosphoric acid	38.79	37.66
Equivalent to bone phosphate	83.68	82.21
Insoluble siliceous matter	8.13	7.39

Analysis of apatite from Arendal, Norway, by G. Rose.

Phosphoric acid (1)	42.229
Fluorine (2)	3.415
Chlorine (3)	0.512
Lime	49.960
Calcium	3.884
	100.000
(1) Equal to tribasic phosphate of lime	92.189
(2) Equal to fluoride of calcium	7.010
(3) Equal to chloride of calcium	0.801

APATITES OF SPAIN.

The only other apatite deposits which have yet become of commercial importance are in Spain. At Malpartida de Cáceres are the mines of Señor Grappin. The mineral occurs in granite, and about six thousand tons annually have been shipped in good years. Considerable deposits of apatite are found at Zarza la Mayor, and at Ceclavin, in the district of Alcantara, near the Portuguese frontier, and about twenty miles from the Tagus. Crystalline apatite is also found in the volcanic rocks at Jumilla, in the province of Murcia, which averages 86 per cent. phosphate of lime.[1] It is also found in the provinces of Alemtejo and Zamora.[2] The Jumilla apatite is often of the yellowish-green variety, known as asparagus stone or Spargelstein.

The Spanish apatite deposits are limited in quantity, compared with the phosphorite deposits of that country, and they have never produced more than a very few thousand tons annually. At present, on account of the disturbed political condition of the country, no apatite is exported.

A description of the other Spanish deposits is given under the subject of phosphorites.

Analyses of Spanish apatite.

[I. Apatite from Zarza la Mayor, by Dr. C. U. Shepard, jr., MSS.]

Tribasic phosphate of lime	79.16
Sand	7.09

[1] O. Ramon T. Muños de Luna: Estudios químicos sobre economía agricola en general, y particularmente sobre la importancia de los abonos fosfatados. Madrid, 1868.

[2] Naranjo y Garza et Lino Peñuelas: Bull. Soc. géologique France, 1860, p. 157.

[II. Apatité from Murcia, by G. Rose.]

Phosphoric acid (1)	42.172
Fluorine (2)	3.434
Chlorine (3)	0.566
Lime	49.894
Calcium	3.934
	100.000
(1) Equal to tribasic phosphate of lime	92.066
(2) Equal to fluoride of calcium	7.049
(3) Equal to chloride of calcium	0.885

PHOSPHORITES.

"The name phosphorite was used by Kirwan for all apatite, but in his mind it especially included the fibrous, concretionary, and partly scaly mineral from Estremadura, Spain, and elsewhere."[1] In this latter sense it is used here, but it will also include certain vitreous and earthy forms which are often so intimately associated with the above-mentioned varieties and which often run into them by such gradations that they are best described together.

The phosphatic deposits of Nassau, in Germany; those of the southwest of France, commercially known as "Bordeaux phosphates," and those of Estremadura and Cáceres, in Spain, come under this head.

PHOSPHORITES OF NASSAU.

The phosphorite deposits of Nassau were discovered in 1864 by Herr Victor Meyer, of Limburg, though as early as 1850 Dr. Sandberger had discovered apatite in the manganese mines of Kleinfeld.

The principal phosphorite deposits occupy an irregular area, bounded on the northeast by the town of Weilburg, on the northwest by the Westerwald, on the east by the Taunus Mountains, and on the south by the town of Dietz. The general appearance of the country is that of a broad plain, intersected by the Lahn and its tributaries. The phosphorite is found in cavities in a hard, massive, dolomitic limestone of the Devonian age. The following section,[2] in an ascending order, will show the geologic relations of the deposits:

(1) Porphyry, dark to light gray and green, containing cavities of calcareous matter.

(2) Slaty and shaly beds, much contorted.

(3) Dark-red sandstone, containing beds of hematite.

(4) Dolomitic limestone, white, blue, or pink in color, resting unconformably on the underlying bed.

(5) Phosphorite deposits.

(6) Brown clay, supposed to be Tertiary.

The phosphorite is sometimes found on the surface and sometimes under as much as two hundred feet of clay. The hollows containing the phosphorite are generally much worn and have all their edges rounded off, as if they had been exposed to the action of water for a long time before the phosphorite was deposited in them (Figs. 22, 23).

[1] J. D. Dana: A System of Mineralogy, 1873, p. 531.

[2] D. C. Davies: Geol. Mag., vol. 5, London, 1868, p. 262.

The phosphatic deposits vary from six inches to six feet in thickness and seem to attain their greatest continuity in a belt running in a northeast and southwest direction, thinning out gradually at both extremities. They seem to occur only with the limestone, and are no longer found when that rock disappears. This would seem to indicate that they depend on the limestone for their origin.

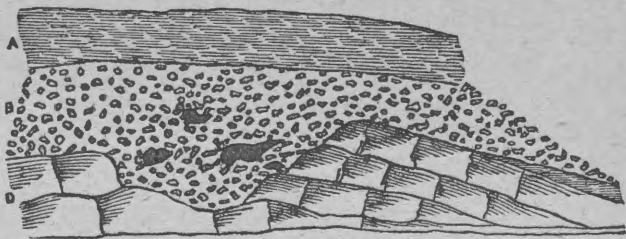


FIG. 22. Section at Cubach, Nassau, Prussia. After D. C. Davies: Geological Magazine, London, 1868. A, clay; B, phosphate of lime; C, manganese; D, dolomite.

The phosphorite is found in a great variety of forms. It is generally massive, fibrous, earthy, porous, jasper-like, kidney-shaped, stalactitic, or nodular. Occasionally there are found in it minute crystals of apatite (Davies). Sometimes, also, it occurs as an incrustation, and it is then known as staffelite, from its abundance near the town of Staffel.

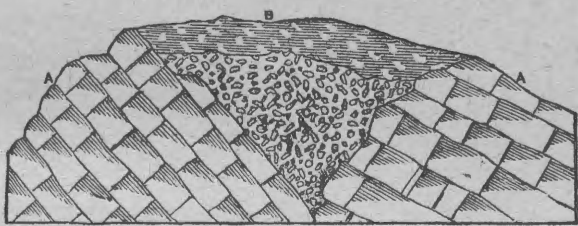


FIG. 23. Section at Staffel, Nassau, Prussia. After D. C. Davies: Geological Magazine, London, 1868. A, dolomite; B, clay; C, phosphate of lime.

This mineral is, generally, white, yellow, green, or brown in color, and occasionally translucent. The other varieties are of almost all colors, white, yellow, red, gray, blue, green, brown, or black. Occasionally a brecciated variety is found, but the larger part of the deposit is of the massive kind.[1] The hardness varies from 1 to 5. With the phosphorite occasionally occur deposits of crystalline hematite and manganese ore. These minerals are most common on the outside edges of the phosphate-bearing area, but are also found with it in the same deposit. The amount of phosphate of lime in the phosphorite is very variable, averaging from 60 to 92 per cent. (see analyses). It is generally richest when associated with the least hematite and manganese and, when free from the former mineral, it makes an excellent superphosphate. Among the other minerals associated with this deposit are wavellite, calcite, quartz, wollastonite, jasper, and chalcedony.

[1] Dr. C. U. Shepard, jr., MS.

There are no signs of organic remains in the Nassau phosphorites, but they are generally believed to be of animal origin. Dr. Mohr thinks they were formed by the concentration of the phosphate of lime from the underlying limestones. At present not much phosphorite is exported on account of the difficulty of freeing it from the associated iron and the expense of mining it. Several years ago, however, large quantities were sent to England, and in 1867 the total output of all the mines amounted to 30,000 tons, which sold, according to its quality, for $5 to $8 per ton. It is still used in considerable quantities along the Rhine.

Table of analyses of Nassau phosphorites.

	Fresenius and Foster.	Fresenius.	Wicke.
	Pure staffelite.	General sample.	General sample.
Lime	45.79	47.31	42.31
Magnesia	0.16	0.12	0.23
Sesquioxide of iron	6.42	3.77	8.22
Alumina	1.08	1 67	2.23
Potash	0.58	0.66	1.26
Soda	0.42	0.52	0.09
Phosphoric acid	34.48	33.84	30.63
Carbonic acid	1.51	2.75	2.78
Silicic acid	4.83	5.04	6.61
Fluorine	3.45	2.11	3.74
Water	2.45	2,74	3.00
Sulphuric acid	....	....	1.07
	101.17	100.53	102.17
Deduction for oxygen	1.45	0.84	1.57
	99.72	99.69	100.60

PHOSPHORITES OF SOUTHWESTERN FRANCE.

The phosphorites of the southwest of France are in the departments of Lot, Tarn-et-Garonne, and Aveyron. The region is limited by the valleys of the rivers Lère, Cellé, and Aveyron, and the phosphorite is found in largest quantities near Caylus and at St. Antonin, Limogne, Cajarc, Figeac, Villeneuve, Bozouls, and other places on the southwestern side of the central plateau. The material occurs in fissures and cavities in the surfaces of hard, compact, gray limestone plateaus which belong to the Oxfordo-Coralline group of the Jurassic formation. The deposits are of two kinds.[1] The first occurs in irregular cavities, never over a few yards long, and partaking more or less of the character of pockets; the second, in the form of elongated leads, with sides which are nearly vertical and which run in a generally parallel direction, widening and narrowing at intervals. They are generally shallow and

[1] Mr. Daubrée: Comptes rendus Acad. sci., Paris, vol. 73, 1871.

thin out very rapidly at a short distance from the surface. They often, however, continue for some distance longitudinally. Thus, at Pendaré, the surface of the phosphate lead is three to ten yards wide and has been followed in a straight line for 100 yards. Any sudden turn or curve in the fissure is, according to Mr. Rey-Lescure,[1] almost sure to make the lead thin and poor. The richest leads are those which run in a straight line and have walls which are smooth and tend toward a vertical position. According to Mr. Daubrée,[2] the fissures seem to follow certain definite directions. Thus, at Pendaré and Mas-Merlin, they run ENE. and WSW. At the same time there is another series of leads running at right angles to these. The phosphatic material of the leads running in different directions is of very different character, as will be hereafter shown.

The phosphorite occurs in a great number of forms. Sometimes it has a rounded, concentric, and radiated structure; at others it occurs in nodular and mammillated masses. Often it is found in agate-like zones, forming twenty to thirty layers in a thickness of a centimeter. Sometimes it occurs as geodes,[3] and at other times it is found in fibrous masses, very much resembling aragonite. The phosphorite varies very much in hardness, compactness, and general appearance. The purest form is as hard as apatite, has a resinous or subvitreous luster and a yellowish-brown color. Sometimes the color is of a light blue, possibly due to the presence of phosphate of iron. The impure varieties are white, yellow, or red, and are often soft and earthy. The phosphorite which occurs in the form of nodules is often hollow in the interior, containing loose stones in the cavities (Daubrée). The whole mass is mixed with siliceous pebbles, clay (more or less ferruginous), loose blocks of calcareous rock, and pisolites of iron, all solidified into a mass varying very much in compactness and generally containing numerous cracks and cavities. Often pyrolusite is associated with the phosphorite, occurring in thin layers or in the form of dendrites. The presence of iodides has been detected, in which respect it resembles the phosphorite of Amberg in Bavaria. Minute quantities of bromides are also found. The presence of pisolites of iron is most frequent near beds of iron ore; and the iron, according to Rey-Lescure,[4] probably has been derived from such beds.

Mr. Trutat has found that in the leads which run ENE. and WSW. the phosphorite is compact, vitreous, agate-like, and, rarely, geodic. In the leads at right angles to these the mass of phosphatic material consists apparently of geodes filled with carbonate of lime or ferruginous clay. The geodes are, however, generally broken and in fragments, so that their contents cannot be observed. The leads of the first variety

[1] Bull. Soc. géologique France, 3d series, vol. 3, 1875, p. 398.

[2] Comptes rendus Acad. sci., Paris, vol. 73, 1871.

[3] Mr. Leymerie: Note sur les phosphorites du Quercy, Toulouse, 1872.

[4] Bull. Soc. géologique France, 3d series, vol. 3, 1875.

generally consist of long fissures with parallel walls, while those of the second variety represent the irregular pockets described by Daubrée. Trutat thinks that the ENE. and WSW. leads were formed first, and that those at right angles to them were formed later, by the action of carbonic acid, which dissolved part of the original leads and redeposited it in new hollows and crevices.

The phosphorite deposits are usually capped by a deposit of ferruginous clay, containing pisolites of iron, bones of land animals, and numerous land and fresh-water shells. Among the bones are the remains of many carnivorous, herbivorous, and omnivorous animals, all mixed together. The bones are well preserved and not affected by chemical action. The deposits of Cregols and Beduer have afforded immense quantities of bones of carnivorous animals, and in the deposits of Raynal, Servanac, and Mouillac are found the remains of many skeletons of anthracotherium, palæotherium, and rhinoceros of several varieties. The bones are also occasionally found embedded in the phosphatic matter itself.[1] Thus, near La Mandine there are so many remains of palæotherium (*P. medium*) that from one cubic decimeter of phosphatized marl four or five fragments of different jawbones and many other bones were obtained. Remains of hyænodon and many land and fresh water mollusks, among them *Planorbis* and *Limnæa*, as well as turtle remains, are found in many deposits. Bones of cainotherium and anoplotherium are of frequent occurrence. Though the rock which contains the phosphorite deposits is of Jurassic age, the phosphate itself is generally believed to be of early Tertiary (Eocene) age. The way in which the phosphorite came to occupy its present position, however, has been a much more disputed point than the time in which the deposit was formed. Daubrée,[2] Rey-Lescure,[3] Leymerie,[4] and others are of the opinion that the phosphate came from mineral springs rising from the bottom of the fissures. The phosphate was dissolved by the action of hot water containing carbonic acid, and, when it came into the fissures, the carbonic acid was lost and the phosphate was deposited. They think the bones are too few to have anything to do with the origin of the phosphate.

Filhol[5] urges against this theory that in all the deposits which have been worked out, and thus afforded a chance of examining the sides of the crevasse, he has found that the phosphate does not run into other leads by narrow necks and veins, as Rey-Lescure asserts, but that the leads are in no way connected with each other and that the crevices show no openings through the limestone which could have served as an exit for the phosphatic solution. Consequently he concludes that

[1] Mr. Daubrée: Comptes rendus Acad. sci., Paris, vol. 73, 1871.
[2] Alph. Peron: Bull. Soc. géologique France, 3d series, vol. 2, 1874.
[3] Bull. Soc. géologique France, 3d series, vol. 3, 1875.
[4] Note sur les phosphorites du Quercy, Toulouse, 1872.
[5] Annales sci. géol., vol. 7, 1876; Recherches sur les phosphorites du Quercy, pp. 1-220.

the deposits were formed by a solution of phosphate of lime in carbonic acid, running from the surface downward into the fissure. When all the fissures were filled the solution often spent its strength in phosphatizing the marl of the neighborhood. Thus at La Mandine Basse they find a calcareous marl containing 25 to 30 per cent. phosphate of lime.

Mr. Combes[1] thinks the phosphate bed was formed by phosphatic vapors rising up through the Jurassic limestone and phosphatizing it. He thinks a similar action is going on at the present time. Mr. Malinowski[2] thinks that the beds are of purely animal origin and that volcanic eruptions of Auvergne killed all the animals of the period and thus furnished the phosphate to fill up the fissures. Mr. Delfortrie[3] thinks the deposit is of Quaternary age and derived from altered guano.

Mr. Peron[4] has shown that the phosphate deposits only occur where the Tertiary deposit now exists or where it has existed in time past. Thus on the Jurassic plateau at Bach, Mouillac, and Malpérie, the Tertiary formation which covers it at Lavaurette, Monpalach, and Lasalle, in Tarn-et-Garonne, has been eroded. Yet both districts are rich in phosphate. On the other hand, at Laussiers and Anglars, where he supposes the Tertiary has never existed, there is no phosphate. He thinks the phosphate deposits are synchronous with the Lower Tertiary of Aude and Tarn. The waters of the Eocene, he supposes, came suddenly over the Jurassic plateau, overwhelming the numerous land animals of the region and sweeping the remains of these and masses of guano into crevices and cavities, together with quartz pebbles, land and fresh-water shells, and other débris. Then the action of time and carbonated waters partially metamorphosed the phosphate and converted it into concretions and other forms of phosphorite in the midst of the clay and bones. At a later time the superficial deposits of bones were laid down.

The strongest arguments of the advocates of the hydrothermic theory are the presence in the phosphorite deposits of iodine and manganese, and of pisolites of iron, which are generally of hot spring origin.

Peron thinks these latter were formed during the deposition of the Lower Tertiary formation. He also calls attention to the fact that phosphorite has nowhere been found in the southwest of France at a greater height above the sea than 320 meters. This he explains by supposing that the waters of the early Tertiary did not extend above this height.

The phosphorites of the southwest of France were discovered in 1865, on the plateau of Quercy, in the department of Lot, by Mr. André Poumarède. Five years later the deposits of Lot-et-Garonne, Tarn-èt-Garonne, and Aveyron were discovered and worked until the last few years,

[1] Phosphorites du Quercy, Revue scientifique, 1872, No. 12.

[2] Traité spécial des phosphates de chaux natifs, Cahors, 1873.

[3] Les gîtes de chaux phosphatée dans le départ. du Lot, Bordeaux, 1873.

[4] Bull. Soc. géologique France, 2d series, vol. 2, 1874.

when the exports ceased. The best deposits had given out and the others contained so much iron and alumina that the material was very undesirable as a source of superphosphate. For several years, from 1870 to 1875, an average of 20,000 tons per annum was exported.[1] Some of the mines are still worked, but the phosphate is used only in a raw state and for local purposes.

Soon after mining had begun in this region, Guillier estimated that the total contents of all the mines would not exceed 100,000 tons. This estimate was much too small, but it serves to show that the deposit is a very limited one. The phosphate was formerly collected in loose bowlders from the fields for the purpose of building walls. At the Pearl mine, near Cajarc, the phosphorite crops out at the surface.[1] At the depth of 75 feet the lead becomes very thin and uncertain. The mass of the phosphorite is, in some places, 10 feet thick, but ordinarily it consists of several more or less parallel bands, which end abruptly.

One of the largest mines is at Larnagol, in the department of Lot. It is situated on the summit of an Oxfordian plateau over a thousand feet high. The first quality rock is cleaned by hammer and hand, and the second quality in a simple horizontal washer, driven by steam. The phosphorite contains both chlorine and fluorine, but in much smaller quantities than exist in apatite. As has been said before, it also contains iodine, and in some specimens traces of bromine have been detected.

Table of analyses of phosphorites from southwestern France.

[I. Analyses by Bobierre.]

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Siliceous sand	1.00	4.70	12.70	12.06	3.00	1.00	1.40	0.93
Phosphoric acid	38.00	32.94	36.48	35.84	36.80	37.10	37.00	38.32
Total lime	51.47	......	......	......	......	......	51.50	48.92
Water volatilized at red heat, fluorine, chlorine, carbonic acid, and oxides of iron and manganese	9.53	......	......	......	......	......	10.10	11.83
	100.00	......	......	......	......	......	100.00	100.00
Lime in excess of phosphoric acid, and combined with carbonic acid, fluorine, and chlorine	6.87	......	......	......	......	......	8.10	3.94

[1] Dr. C. U. Shepard, jr., MS.

Table of analyses of phosphorites from southwestern France—Continued.

[II. Analyses by C. U. Shepard, jr.]

	High-grade phosphorite, from Mas-Merlin.	Low-grade phosphorite, from Larnagol.
Phosphoric acid	38.64	21.46
Equal bone phosphate	84.35	46.85
Sand	1.00	14.58

Superphosphates made from 12 parts (by weight) of rock and 9 parts of sulphuric acid (1.50 specific gravity) gave:

High grade .... 14.98 per cent. soluble phosphoric acid.
Low grade .... 5.04 per cent. soluble phosphoric acid.

[III. Analyses of commercial Bordeaux phosphate by C. U. Shepard, jr.]

	I.	II.
Phosphoric acid	35.46	34.45
Equal bone phosphate	77.41	75.20
Sand	4.35	8.55

Superphosphates made in the same way as the last case gave:

	I.	
Soluble phosphoric acid	15.00	12.48

PHOSPHORITES OF SPAIN.

The phosphorite deposits of Spain are situated near the towns of Logrosan and Cáceres, in Estremadura. The two localities differ somewhat in the mode of occurrence of the phosphorite as well as in its physical properties, and will therefore be treated separately.

Logrosan deposits.—The country in which these occur is a broad tableland composed of a clay slate and studded here and there with conical peaks rising abruptly from the level of the plain, and often reaching the height of three hundred to six hundred feet above the surrounding surface. There also occur numerous long, flat ridges, rising, like the peaks, abruptly from the surface of the plateau. The slate is of very variable character, being composed sometimes of a dark-blue, fissile schist, sometimes of a micaceous or a talcose schist, and at other times of alternating beds of talc and feldspar.[1] No fossils are found in this formation, but in a very similar deposit near Almaden, and about eighty miles from the town of Logrosan, are found numerous fossils,

[1] Charles Daubeny and Captain Widdrington: Jour. Roy. Agric. Soc., 1845.

such as *Spirifer attenuatus* and trilobites. Consequently the slate formation of Logrosan and Cáceres has been referred by some French and Spanish geologists to the Silurian formation. Le Play[1] refers it to an older formation than the fossiliferous slates of the neighborhood of Almaden. The conical peaks rising up from this formation are granitic intrusions. They are very feldspathic and often much weathered. In this latter respect they differ from the long, flat ridges spoken of above. These are beds of quartzite interstratified with the country rock, which has a quite regular, almost vertical dip. The quartzite is sometimes very compact and homogeneous and at others it is granular and often resembles a sandstone. It has resisted the erosive action, which has worn down the more easily attacked parts of the slate formation and now stands out in bold, angular ridges. The section (Fig. 24) from Truxillo to Logrosan, a distance of seven Spanish leagues, will show the general character of the country. Besides the rocks already mentioned, large veins of dark limestone are occasionally found cutting through the slate formations.

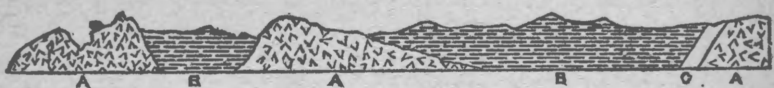


FIG. 24. Section from Truxillo to Logrosan, Spain, after Daubeny and Widdrington. A, granite; B, slate; C, phosphorite.

The phosphorite occurs in true veins and in pockets. Occasionally it occurs as a vein at the line of junction of the granite with the country slate. It is of a variable character, occurring sometimes in an amorphous and compact form, at others in a fibrous or concretionary state, often inclosing pebbles of white or ferruginous quartz. It varies in color from white and yellow to a rich, jasper-like red. It is often covered with dendrites of manganese, and occasionally agate-like varieties are found in which the phosphate is interstratified with bands of lilac amethyst. The palmated variety is generally the purest and the most abundant. It has a hardness of 5.5, and a specific gravity of 3.12. When heated in a darkened room it gives off a bright phosphorescent light.[2]

At Logrosan there are six principal deposits of phosphorite. They are known as Costanaza, Jungal, Castillon, Angustias, Terrenos Colorados, and La Cambre Bojera. The Costanaza vein is by far the largest phosphorite vein known in all Spain, and perhaps in the world (Shepard).[3] It extends for about two and a half miles from the foot of Mt. Boyales, on the north, in a southeasterly direction past Mt. Cristobal. The vein dips at an angle of 60° to 90° toward the east (Garza and

[1] Annales des mines, 1836.

[2] Sur la phosphorite de Logrosan, Estremadura, Messrs. Naranjo y Garza and Lino Peñuelas: Bull. Soc. géologique France, 1860, vol. 17, p. 157.

[3] Foreign Phosphates, 1879, p. 25.

Peñuelas), and cuts obliquely through the country slate, which has a strike of north 15° to 45° east, and a dip of 70° southwest. The vein has been worked principally where it crosses hills, and especially near the chapel of Nuestra Señora del Consuelo. It varies from ten to twenty feet in width and contains streaks of quartz and horses of country rock. The walls of the slate show signs of considerable decomposition and disintegration. The vein thins out at each end, and also grows narrow at a depth; though, as the excavation is only about forty feet deep, the bottom has not yet been reached.[1]

The second vein, Jungal, is at the entrance of the town of Logrosan, on the road to Truxillo. It has a mean width of 32 inches and a length of one thousand to twelve hundred feet. In most respects it resembles the Costenaza vein, but is on a much smaller scale.

The Castillon vein runs under the town for a considerable distance and varies in width from five to six and three-fourths feet. It presents a mass of phosphorite of great purity.

The Angustias lead is on the side of the hill Nuestra Señora del Consuelo and runs towards Mt. Boyales. It is not so valuable as some of the other leads, because of being much cut up by quartz veins and horses of country rock.

The Terrenos Colorados vein is 330 feet long and averages six and two-thirds feet wide. It is parallel to the Cambre Bojera lead, which is about the same size.

The general direction of all these veins is northwest and southeast, with a dip of 60° to 90°.

The Logrosan phosphate has a subcrystalline structure; some specimens are fibrous and radiating and often resemble feathers. It is soft and chalky to the touch, easily broken, but difficult to grind into a fine powder. An examination under the microscope exhibits conchoidal figures interrupted with spherical grains, devoid of color and opaque (Shepard). It is infusible before the blowpipe; but, on being subjected to long-continued heat, a luminous disk, perceptible in the dark, makes its appearance at the point of contact of the mineral and flame; and a green phosphorescence appears when it is heated for a short time. It is readily soluble in hydrochloric, nitric, or sulphuric acid.

The highest-grade material is rosy white or yellowish white in color, soft, concentric, often brilliantly radiated, with a mamillary or conchoidal surface. Red spots from iron and beautiful dendrites of manganese are not infrequent. The poorer qualities are milky white, vitreous, hard, and, though free from limestone, contain considerable silica.

The shipment of phosphate from Logrosan involves great trouble and expense. The mineral is drawn by ox or mule teams to the nearest railroad, a distance of 30 miles, and is shipped at Villanueva de la Serena. This carriage costs about 20 cents per cwt., and the carts make two

[1] Dr. C. U. Shepard, jr., MS.

trips a week, carrying 40 to 50 cwt. each trip. This, with the expense of getting it to Lisbon and thence to England, makes it cost about $15 a ton to land in London. First-class phosphorite (80 to 85 per cent.) sold there, in 1875, for $25 a ton.

In the Cáceres district, which supplies most of the phosphorite shipped from Spain, the mode of its occurrence differs from that in the Logrosan district. While in the latter it occurs in veins, sometimes of considerable length, at Cáceres it occurs in pockets in great veins of quartz and dark limestone, which are found cutting through the country slate. The principal mines are united in the Fraterjidad Company, and are known as the Esmeralda, Estrella, San Eugenio, Abundancia, Cacereña, San Salvador, and La Perla.[1] The first four, being the only mines of much importance, will alone be described. As will be seen from the ground plan (Fig. 25), the limestone and quartz veins, in which the phosphate is found, occur in both the granite and the slate rocks.

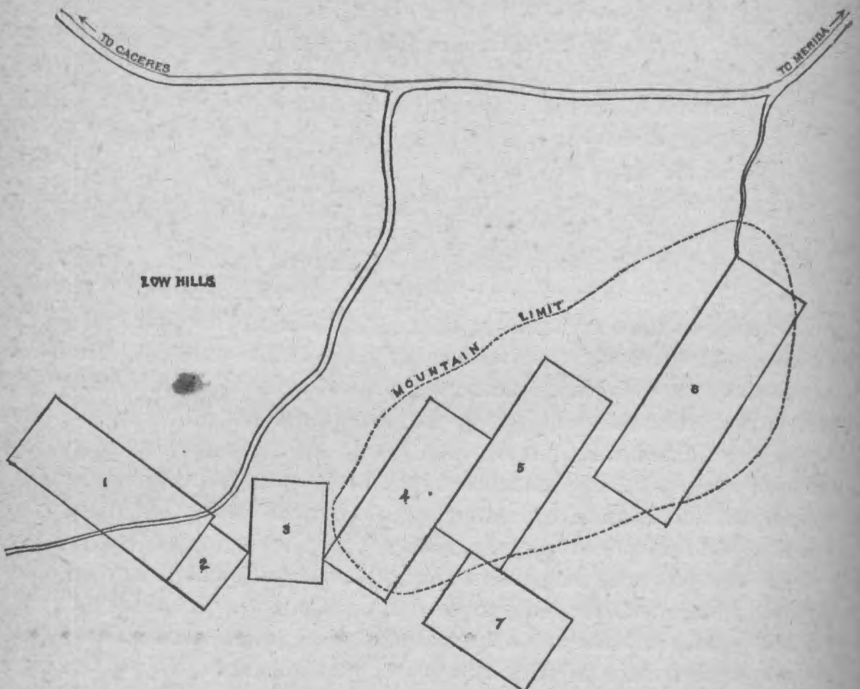


FIG. 25. Ground plan of the Cáceres mines in 1875; after Dr. C. U. Shepard, jr. (MS.). 1, Abundancia mine; 2, Carcereña mine; 3, San Eugenio mine; 4, San Salvador mine; 5, Estrella mine; 6, Esmeralda mine; 7, La Perla mine.

The Esmeralda mine is considered the largest and best of the Cáceres mines. There are two veins penetrating the side of a hill in a north

[1] C. U. Shepard, jr., MS.

and east direction, respectively, at an angle of about 45°. The vein to the north has a thickness of ten to twenty feet, and contains a variable quantity of limestone and siliceous rock. The immediately surrounding rock is limestone of a hard, brown character, which has been excavated for a depth of some one hundred feet (1875). The leads appear to narrow as they are followed into the hill. The exterior of the mass of phosphate is hard, white, and compact, while toward the center it becomes soft, crumbly, and of a rosy color (Shepard). There is less hard, siliceous rock here than in the other mines.

At the Estrella mine the lead enters the hill in which the Esmeralda mine is situated at an angle of 45°. The total thickness of the deposit is ten to twenty feet. It is very irregular in shape and grows thinner as it enters the hill. It contains less of the rich, pulverulent variety of phosphorite and more of the compact, vitreous variety than the last mine. Like the Esmeralda mine, it is in a limestone vein (Fig. 26).

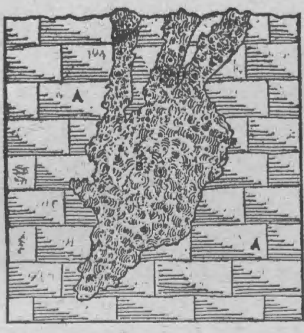


FIG. 26. The Estrella deposit in Estremadura, Spain; after C. U. Shepard, jr. (MS.). A, limestone; B, phosphorite.

The San Eugenio mine is smaller than either the Esmeralda or the Estrella. The lead is almost vertical and the phosphorite in some places is of a very high grade, but in others it is very siliceous and impure.

The Abundancia mine has been abandoned on account of the trouble from water. It is simply a round open pit 75 feet deep and 100 feet in diameter. It once gave large quantities of excellent phosphorite, but what is now left is siliceous and contains only 50 to 65 per cent. phosphate of lime, while the best Spanish phosphate will average 80 to 85 per cent. (See analyses pp. 58, 59.) The Cáceres phosphate is massive and amorphous and of two varieties: (1) Somewhat granular, easily crumpled, and of a white or rosy color; (2) dense, vitreous, hard, and white, with occasional streaks of quartz or limestone.

Cáceres is 43 miles north of Merida, a station on the railroad between Madrid and Lisbon, and near the Portuguese frontier. The cost of transportation between the two places varies from 12½ to 20 cents per cwt. Thence to Lisbon costs $4.55 per ton, making the total cost to Lisbon amount to $5 to $8 per ton. The Cáceres mines were not opened until 1860, and from that time until 1875 the mines had exported only 124,156 tons of phosphorite.

The Logrosan deposits were the first phosphorites found in Spain. The earliest mention of them is by William Bowles in 1782.[1] He says that at the base of the Guadalupe Mountains, and near the town called Logrosan, the royal road is traversed by a vein of phosphoric stone, running in a north and south direction. It was also mentioned by La Play, Proust, and others in the early part of this century. But the deposit did not attract much attention until Professor Daubeny, of Oxford, and Captain Widdrington[2] visited the Logrosan country in 1844 and made a thorough study of the one vein then known. Later, in 1849, Mr. Naranjo y Garza, by order of the Spanish government, made a survey of the basin of the Guadiana and gave a description of the Logrosan phosphate deposits.[3]

The Cáceres deposits were discovered in 1860 by Mr. R. De Luna.

Ever since about 1855 the Spanish phosphorites have been worked at intervals. The phosphorite is of excellent quality, commands a high price, and makes as good a superphosphate as any phosphate known. But the expenses of transportation and the occasionally unsettled political condition of the country have been great detriments to the development of the mines.

Analyses of phosphorites of Spain.

[I. Logrosan phosphate, by De Luna.]

Water	0.40
Bone phosphate of lime	82.10
Phosphate of iron	5.20
Phosphate of magnesia	0.30
Fluoride of lime	7.31
Carbonate of lime	1.74
Chloride of lime	0.40
Silica	2.55
	100.00

[II. Logrosan phosphorite, by Professor Daubeny.]

Silica	1.70
Protoxide of iron	3.15
Fluoride of lime	14.00
Phosphate of lime	81.15

[III. Logrosan phosphate, by Messrs. Pelletier and Donadei.]

Phosphoric acid	40.12
Silica and clay	3.10
Hydrochloric acid	0.06
Hydrofluoric acid	2.27
Lime	53.50
Peroxide of iron	0.61
Loss	0.79

[1] Natural History and Physical Geography of Spain, Madrid, 1782.

[2] Quart. Jour. Geol. Soc. London, vol. 1, 1845, pp. 52–55.

[3] La Gazette de Madrid, July 22, 1849. Revista Minerva (March and July, 1855).

[IV to VII. Logrosan phosphate, by Dr. C. U. Shepard, jr., and Dr. Wamer.]

	IV. White and hard.	V. Yellowish white and hard.	VI. Rosy white and compact.	VII. White, soft, and mammillary.
Phosphoric acid	36.97	37.55	42.17	41.72
Equal bone phosphate	80.71	82.97	92.06	91.09
Sand and insoluble matter	12.63	7.40	Trace	4.32

[VIII to XIV. Cáceres phosphate, by Dr. C. U. Shepard, jr., and Dr. Wamer.]

	VIII. Rosy and pulverulent.	IX. White and hard.	X. Rosy and pulverulent.	XI. White and hard.	XII. San Eugenio.	XIII. Abundancia.	XIV. Mina Rosa, at Malpartida de Cáceres.
Phosphoric acid	37.38	32.06	38.07	29.09	39.07	27.00	36.18
Equal bone phosphate	81.60	69.99	83.11	63.50	85.29	58.94	78.98
Sand	3.40	22.97	6.30	2.70	9.19	3.76	Trace

[XV. Cáceres phosphate, by Bobierre and Friedel.]

Insoluble siliceous matter	21.05
Water expelled at red heat	3.00
Tribasic phosphate of lime	72.10
Loss, oxide of iron, etc	3.85
	100.00

[XVI. Phosphate from Montanchez, by Bobierre and Friedel.]

Tribasic phosphate of lime	85.03
Carbonate of lime	10.35
Water expelled at red heat	2.40
Silica, oxide of iron, etc	2.22
	100.00

Phosphorites include, besides those deposits already mentioned under that heading, the minerals staffelite, epiphosphorite, pyrophosphorite, eupyrchroite, hydro-apatite, monite, monetite, and other forms, all of which occur either in scattered pockets, incrustations, and concretions, or as radiated, botryoidal, and subcrystalline masses. Some of them occur scattered through certain phosphorites and rock phosphates, and are mentioned in connection with those deposits. They are rarely of any commercial importance.

Fibrous and concretionary phosphorites have been mined in small quantities at Amberg, Bavaria.

Thin seams of soft, whitish phosphorite, called osteolite, occur at Hanau, in Germany, but, as yet, the mineral has not been found there in sufficient quantities to be of commercial value.

ROCK PHOSPHATES.

This class of phosphates includes, as already mentioned, those deposits which, having no definite chemical composition and lacking the homogeneous nature and other fixed characteristics of a true mineral, cannot be classified with *mineral phosphates.* They may be treated as *amorphous nodular phosphates*, *phosphatic limestone beds*, *guanos*, and *bone beds.*

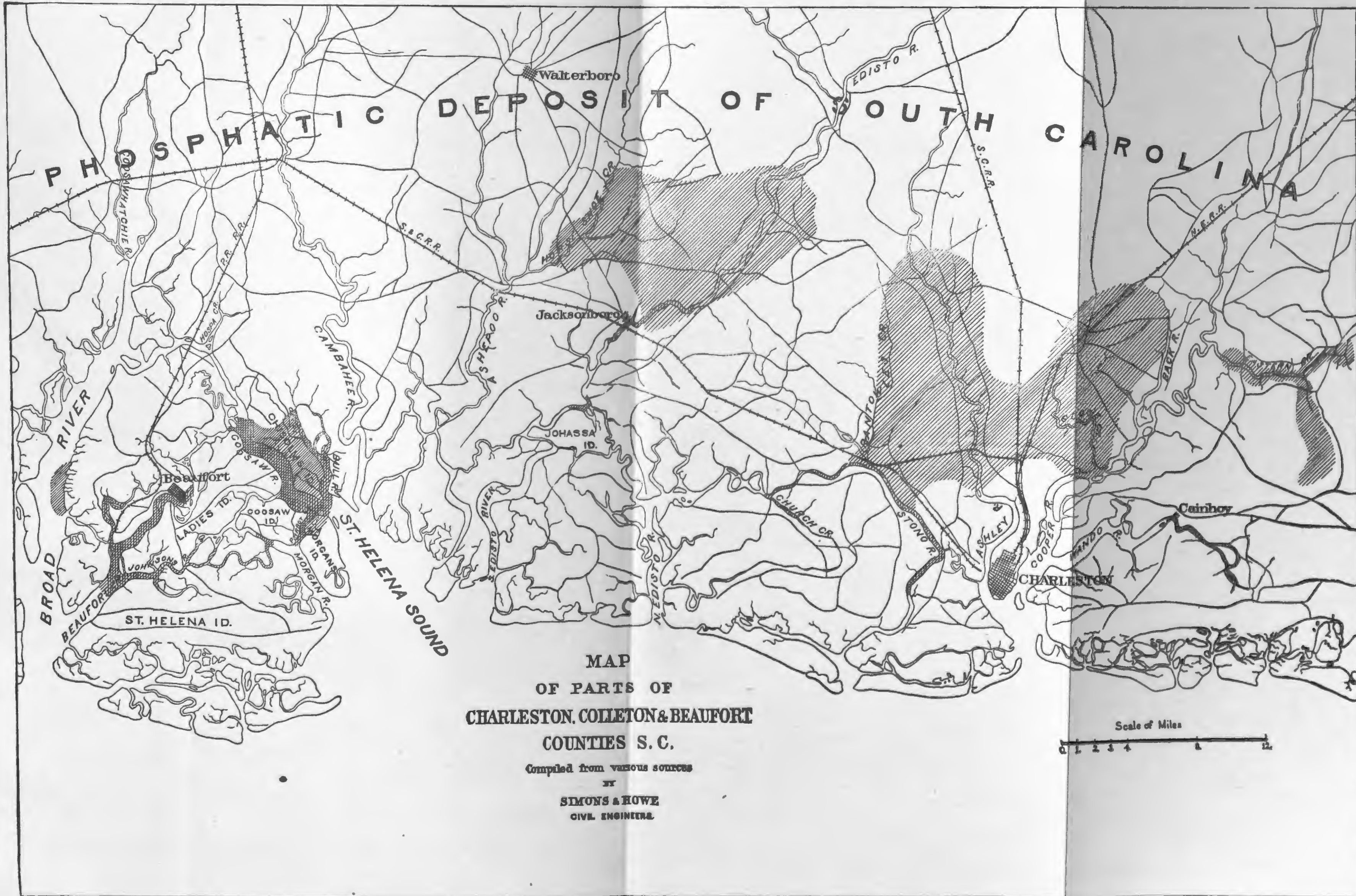
AMORPHOUS NODULAR PHOSPHATES.

This subdivision comprises the phosphate deposits of South Carolina, North Carolina, Alabama, Martha's Vineyard, some of the Florida deposits, the deposits of North Wales, England, Belgium, northern central and eastern France, and Russia. They generally consist of calcareous matter, more or less completely phosphatized, and occur either as loose nodules in a matrix of variable composition, or as a conglomerate in which the pebbles are phosphate of lime and the matrix is of a calcareous, phosphatic, siliceous, or ferruginous nature. They are the most important, commercially, of all the phosphate deposits. About 600,000 to 700,000 tons are yearly mined, of which, in 1884, 437,000 tons came from South Carolina and the rest mostly from England, France, and Belgium. On the other hand, the total output of all the apatite mines in America and Europe in the best years has not exceeded 50,000 tons.

AMORPHOUS NODULAR PHOSPHATES OF SOUTH CAROLINA.

The nature of the phosphate beds of South Carolina was recognized by Prof. C. U. Shepard, sr., before 1860, but the nodules were not put to any practical use until, in 1867–'68, Prof. F. S. Holmes and Drs. Pratt and St. Julien Ravenel, after showing by numerous analyses their richness in phosphate of lime, urged the formation of a company for mining these valuable deposits. Through the energy of Professor Holmes and Mr. G. T. Lewis, of Philadelphia, the first company for mining phosphate in South Carolina was organized in 1868. It was known as the Charleston Phosphate Mining and Manufacturing Company. Since that year no less than fifteen large mining establishments have been started in South Carolina, of which some of the more important are the Bradley, Pinckney, and Bolton, in Berkeley County, and the Coosaw and Oak Point properties, in Beaufort County.

Nodular phosphatic deposits are found at intervals all along the Atlantic Coast of the United States, from North Carolina down to the southern extremity of Florida, but the richest beds occur in South Carolina, in a strip of country running from Broad River 60 miles along the coast in a northeast direction. The belt has a width of from ten to twenty miles. The phosphate does not occur continuously over this region, but in patches, sometimes having an area of many square miles and again only covering a few acres. In this whole area of more than nine hundred square miles, the hills rarely rise to a height of over ten to fifteen feet above high-water level, and the country is cut up into islands and peninsulas by the numerous tide-water inlets and creeks. The Tertiary deposits form a fringe along the Atlantic Coast and the Gulf of Mexico from New Jersey to Texas, but are best developed in the


PHOSPHATIC DEPOSIT OF SOUTH CAROLINA
Walterboro
Jacksonboro
Beaufort
Charleston
Cainhoy
EDISTO R.
S.C.R.R.
N.E.R.R.
P.R.R.
BROAD RIVER
BEAUFORT R.
ST. HELENA ID.
LADIES ID.
COOSAW ID.
COOSAW R.
MORGANS ID.
MORGAN R.
BULL R.
ST. HELENA SOUND
CAMBAHEE R.
ASHEPOO R.
JOHASSA ID.
EDISTO RIVER
N. EDISTO R.
CHURCH CR.
STONO R.
ASHLEY R.
COOPER R.
WANDO R.
BACK R.
JOHNSONS
COOSAWHATCHIE R.
HORSE SHOE CR.
PANTON R.
MAP
OF PARTS OF
CHARLESTON, COLLETON & BEAUFORT
COUNTIES S. C.
Compiled from various sources
BY
SIMONS & HOWE
CIVIL ENGINEERS.
Scale of Miles
0 1 2 3 4 8 12

central portion of this extensive belt. The Claiborne marls, the Santee buhrstones and limestones, and the shell sands of Alabama are the lowest beds of this series. Beneath them lie the Pedee marls, which belong to the secondary formation and contain fossils resembling those from the Chalk of Europe. Immediately over this formation in South Carolina are the Eocene marls. These beds are very extensively developed in that State and are called by Mr. Ruffin "The Great Carolina marl bed," which is divided into three divisions, known, in an ascending order, as the Santee River, Cooper River, and Ashley River beds. The whole formation is about seven hundred feet deep and contains 55 to 95 per cent. of carbonate of lime. It is one of the most important marl beds in the world, on account of both its extent and its agricultural value. The upper part of the Ashley marl contains a great number of fossil shark teeth and cetacean bones, and has been called by Professor Tuomey "the fish bed of the Charleston basin." Overlying this "fish bed" is a deposit of sands and clays of very irregular thickness and containing many shells. The bed sometimes runs out altogether and at other times is several feet in thickness.[1] It is directly overlaid by a bed containing many shark teeth and cetacean bones, as well as the remains of the mastodon, megatherium, elephant, deer, horse, cow, hog, muskrat, and other land animals. Besides these animal remains, the bed contains very numerous irregularly shaped nodules containing 25 to 70 per cent. of phosphate of lime. This is the bed that is worked for phosphates (see Figs. 27, 28, and 29). Sometimes the underlying stratum has not existed or has been eroded and the nodule bed rests directly on the Eocene marls. It is composed mostly of nodules, associated with a much smaller and very variable quantity of bones of land and sea animals, buried in a matrix of a variable character. Sometimes they are in a bed of highly siliceous sand, containing many flat pebbles of white quartz; at other times the matrix consists of ordinary clay or of sand and clay mixed. A light blue or green clay is also often seen.

The nodules are of very irregular shape and vary from the size of a pea to that of a mass weighing a ton or more. The larger masses, however, are often composed of a number of small nodules cemented together. With the nodules and the bones are associated numerous phosphatic casts of the interiors of shells, as well as masses, of rare occurrence, which have the appearance of fossil dung (coprolites). The nodules, like those of England and of France, are all more or less waterworn and rounded and are much bored by marine animals. It is generally the harder varieties that are most bored and most irregular in shape. This may be due to the fact that, being hard, they preserve their original irregular shape and the marks of the boring animals better than the softer varieties. The nodules vary in hardness from 2 to 4 and have a specific gravity of 2.2 to 2.5.[2] When a fragment is rubbed,

[1] F. S. Holmes: The Phosphate Rocks of South Carolina.

[2] Dr. C. U. Shepard, jr.: South Carolina Phosphates.

or, better, when two fragments are rubbed together, they give off an odor of decayed organic matter. They are marked by a complete absence of crystalline structures, though in some rare cases, as in the Bull River phosphate, a distinct concretionary structure is observable. The nodules generally contain casts of Eocene shells and, in some cases, marine bones and shark teeth. The bones of land animals, though mixed with the nodules, are never found embedded in them, showing that these bones were probably deposited after the formation of the nodules.

The nodules are found on the bottoms of most of the rivers running through the phosphate district, having been washed out of their original beds. These river deposits in many cases have proved to be of great commercial value. The nodules are, as a rule, of a much darker color than those of the land and are often black. They are sometimes very siliceous, the separate grains of sand being plainly visible to the naked eye. These grains are due to the sand in the marl before it was phosphatized. Such seems to have been the case with much of the Beaufort River phosphate. In some cases, however, the siliceous matter is probably due to the replacement of some of the carbonate or phosphate of lime in the original nodule by silica, and the result has been to make the nodule much harder. Such a silicifying action was probably due to the presence of soluble silicates in the river waters. In some places, as at the Bolton mine, the land nodules are also very siliceous, and possibly became so by having once formed the bottom of a river or a bay.

At least eleven varieties of nodules, differing much in their physical character, and often in their chemical composition, may be distinguished among the phosphates taken out of the South Carolina beds. These are:

(1) A jet-black variety with a bright, shining, glossy enamel of the same color. It is very rare and generally occurs in small patches. It contains numerous fossils and shells. It is found in Parrot Creek (see map, Pl. I).

(2) A brown variety with a bright enamel of the same color. It is very rich and is found in considerable quantities at the Bradley mine and on the land of the Charleston Mining and Manufacturing Company.

(3) A light-brown variety with little or no enamel. It bleaches white when exposed to the sun and is found on the land of the Bradley Company, of the Charleston Mining and Manufacturing Company, and in many other localities.

(4) A light, chalky variety containing many shells and generally poorer in quality than the varieties mentioned above. It is very widely distributed over the South Carolina phosphate region, and is simply marl which has not been so highly phosphatized as the harder and darker varieties.

(5) A dark grayish-black variety with little or no enamel. It is very siliceous and contains many shells. It is generally found in rivers, and is especially characteristic of the Stono River district.

(6) A gray variety composed of a mass of shells and transparent siliceous sand, cemented together by a phosphatic cement. Sometimes shark teeth are included in the mass. At times it is hard and compact, and at others it is loose, soft, and porous. Such varieties are found in large quantities in the Beaufort River. They are often mixed with a much better quality of nodule which raises the average phosphatic contents.

(7) A dark-gray, phosphatic conglomerate, in which the pebbles are quartz and feldspar, varying from the size of a mustard seed to that of a buckshot. The matrix is a dark-gray, phosphatic marl. This variety is very rare in South Carolina, but is found in small quantities in the Bull River district.

(8) Nodules having a black enamel and a light or dark gray interior. They contain many shell casts and are found in the Coosaw River and on the Edisto River at Fishburne's mine.

(9) A variety consisting of a mass of concentrically laminated nodules cemented together with a matrix of marl containing many shells. This variety is rare and was found only in the Bull River. It is generally rich in phosphatic matter.

(10) A ferruginous, rusty-brown variety, very siliceous and of poor quality.

(11) Brown or black masses having the general appearance of fossil dung (coprolites) and probably of that nature. They are hard and very rich in phosphate of lime. Real coprolites are of rare occurrence.

Occasionally large, flat, non-concretionary masses are found, which are highly phosphatized on the upper side, while toward the lower side the mass grows poorer and poorer in phosphates, until it differs but little in composition from the underlying marl. In such cases the phosphatized part of the rock is of a darker color than the other part. The upper side is also much smoother and harder than the lower side, which is often very jagged and is sometimes almost as soft as the underlying marl. This formation shows that in some cases at least the phosphatization has gone from above downward. Such a process is also proved by the fact that the marl immediately underlying the phosphate bed contains sometimes 20 to 30 per cent. of phosphate of lime,[1] while this quantity decreases with the depth until, at a few inches below the nodule bed, it contains only 10 to 20 per cent. According to Professor Holmes, the marl is much richer in phosphate of lime in those places where it is overlaid by nodules than where no nodules are found.

Some of the varieties of nodules have been found to grow poorer in phosphoric acid as the center of the mass is approached. This is espe-

[1] Dr. C. U. Shepard, jr.: South Carolina Phosphates.

cially true of those nodules which are coated with an enamel, it being invariably the case that the hard, enamel-like crust is much richer than the soft and less compact interior. In this peculiarity the South Carolina nodules resemble many of those of England and the other phosphate localities in Europe. The phenomenon is dwelt on as one of the strongest arguments for the theory originated by Professor Holmes, that the nodules have been formed by the phosphatization of lumps of

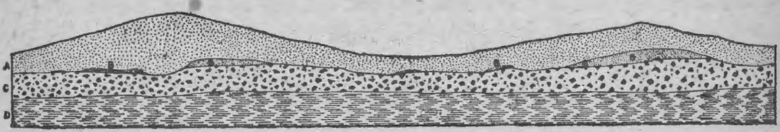


FIG. 27. Section ENE. and WSW. through Pinckney's phosphate field, South Carolina. A, sand; B, ferruginous sand; C, phosphate rock; D, Ashley marl. Scale: 1 inch = 60 feet.

marl. It may, however, be mentioned that a similar condition of the nodule could be produced by the action of waters containing carbonic acid, which would tend to leach out the carbonate and leave the less soluble phosphate of lime. Of course this action would be more pronounced on the exterior than in the interior of the nodule, and consequently the result would be a mass much richer in phosphate of lime on the outside than in the inside.

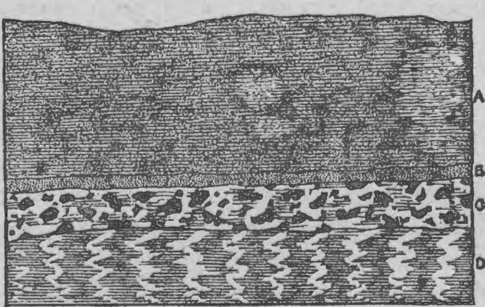


FIG. 28. Average section in Pinckney's phosphate mine, Berkeley County, South Carolina. A, clay sand; B, ferruginous sand; C, phosphate rock; D, Ashley marl. Scale: 1 inch = 6 feet.

The nodule bed varies in thickness from a few inches to about two feet and a half, the average being about seven to nine inches. It is only when the nodules are found in a pocket or depression in the underlying marl that the thickness reaches much over two feet, and even under such circumstances such a thickness is of very rare occurrence. The yield of phosphate per acre varies, not only with the thickness, but also with the compactness of the nodular stratum, as sometimes the nodules are packed as close as cobblestones in a road, while at others they are scattered loosely in the sand or clay matrix. The average yield of clean, dry phosphate is three hundred to twelve hundred tons per acre. The phosphate bed is thought by professor Holmes to be of Post-Pliocene age. In some places it crops out on the surface and at others is found at a much greater depth. Under the city of Charleston it is found at a depth of over sixty feet.[1] Where the bed does not appear on the surface it is covered by alluvial deposits, consisting of clay, sand, or marl, or of strata of all three. Occasionally there is a stratum of highly ferruginous sand or gravel, sometimes indurated into a regular "hard-pan," directly overlying the phosphate bed and from one to ten inches thick (Figs. 27, 28, and 29). Sometimes this ferruginous substance has penetrated the whole bed to a depth of several inches and cemented the upper nodules into a solid mass; while the lower part of the bed is much looser and more easily mined. Again the sand overlying and intermixed with the nodules has sometimes been cemented together, especially in river bottoms, by the action of soluble silicates. Such has been the case with the phosphate in parts of the Stono River. Here the nodules have in some places been completely permeated by silica and form a solid floor on the river bottom.

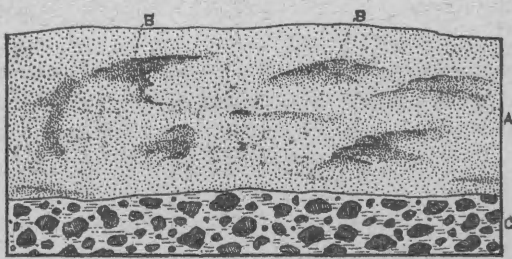


FIG. 29. Section in one of Fishburne's pits, South Carolina. A, sand; B. ferruginous sand; C, phosphate nodules in clay matrix. Scale: 1 inch = 7 feet.

The following sections by Dr. C. U. Shepard, jr., show the general mode of occurrence of the superficial beds of phosphate:

A. Land deposits:

I. *Soil and subsoil.* A few inches to a foot in depth.

II. *A light-colored, siliceous clay,* iron stained in places, and containing much fine, transparent sand, and minute scales of silvery mica, with little calcareous matter, one foot or more in thickness.

III. (Wanting in the more superficial beds.) *A blue, argillaceous marl,* probably altered marsh mud. It does not adhere to the tongue or give an argillaceous odor. Fragments of recent shells occur in this deposit. Its depth is about two feet.

IV. *A thin layer of coarse sand,* one to three inches in depth.

V. *The phosphate nodules* in either a loose, siliceous or a tenaceous, bluish or rich buff-colored, argillaceous marl, frequently accompanied with abundant fossil bones and teeth. The upper nodules are often harder, the lower softer, and at some land localities exhibit a gradual transition, by loss of cohesion and decrease of phosphatic contents into

VI. *A marl,* highly phosphatic toward the rock-bed, and containing occasionally 20 to 30 per cent. of phosphates, but at the depth of a few inches containing only 10 to 20 per cent. of those constituents.

[1] Dr. C. U. Shepard, jr.: South Carolina Phosphates.

VII. *Argillaceous or arenaceous marls*, containing 7 to 10 per cent. of phosphates.

B. River deposits:

Beneath the river deposits occur either—

I. *A gray marl*, sometimes in nodules resembling phosphate, with 5 per cent. of phosphates, underlaid by

II. *A white, hard marl* inclosing phosphate grains and containing 3 to 5 per cent. of phosphates (Wando River); or

I. *A green sand* with some clay and rich in black phosphatic grains, occurring with the phosphatic rock and beneath it, containing 15 per cent. of phosphates,

II. *Soft and hard marls* several feet in thickness, and containing 10 to 15 per cent. of phosphates (Stono River); or

I. *Hard marls*. Poor in phosphates ($\frac{1}{2}$ to 1 per cent.) unless their tops be coated with phosphate rock (Coosaw River).[1]

It is difficult to calculate the yield of river nodules per acre, as the currents have heaped them up in some places and carried them away from others.

As will be seen from the accompanying map by Dr. C. U. Shepard, jr. (Pl. I), there are three principal localities in the phosphate region where active mining operations are now carried on. It is not, however, all over these areas, but only in certain parts of them, that the nodules are found. Nor are they the only places in South Carolina where phosphates occur, but they are the districts where they are found at a depth beneath the superficial deposits not too great to permit profitable mining.[1] The first of these regions lies north and east of Charleston and stretches from the Wando River and the eastern branch of the Cooper River on the northeast to Rantowles Creek and Stono River on the southwest. In this area are some of the largest phosphate diggings in South Carolina, including as it does the Bradley, Charleston Mining and Manufacturing, the Magnolia, Bolton, and Black and Williams's mines. There also are the river deposits in the Wando, Stono, and Cooper Rivers. Large quantities of small nodules of excellent quality have been obtained from the bed of the upper part of the Wando River. Phosphate of good quality has also been gotten from the bed of Stono River, but the deposit forms in some places such a solid floor on the river bottom that mining operations at the present low price of phosphate would be unprofitable. Mainly on account of their inaccessibility the deposits in the eastern branch of the Cooper have not been much worked.

The second of the three principal phosphate districts is due west of the locality last described and extends from the Edisto River on the east to Horseshoe Creek on the west, including the river deposits in these two streams. The phosphate found in this region is of excellent quality, but does not occur in a continuous bed or at a constant depth. Consequently it can be profitably mined in few places. It occurs largely in pockets and patches on the underlying bed.

The third locality where phosphate exists at a conveniently accessible depth extends with intervals from the Bull to the Broad Rivers, and

[1] Dr. C. U. Shepard, jr.: South Carolina Phosphates.

includes not only the deposits in these rivers, but also the deposits in the Coosaw and Beaufort Rivers and those on Chisholm's Island. This area is essentially a river mining district, though phosphate of good quality is mined on parts of Chisholm's Island by the Pacific Guano Company and by Messrs. Wiley and Gordon. Nodules of excellent quality are obtained from the bottoms of the Bull and Coosaw Rivers, but those of Beaufort River are generally very siliceous, the separate grains of sand being plainly visible to the naked eye.

Outside of the localities mentioned above, phosphatic nodules have also been obtained from the upper part of Hospa Creek and from the Coosawhatchie River (see map, Pl. I). Besides the bed of phosphatic nodules already described, other beds have been found in boring artesian wells in Charleston and the neighborhood which are at a much greater depth and are of a similar nature. Dr. C. U. Shepard, jr., in speaking of these borings, says:

The samples thus collected have been carefully examined and analyzed, the most important contribution to our knowledge being the discovery of the existence of several deeper layers of phosphate rock, occurring at the depth of 300 feet from the surface, and, in the form of isolated pebbles, to a much greater distance. These lower deposits are probably not thicker than a few inches, and consequently they lack all but scientific interest.

The phosphate of South Carolina is obtained from the land and from the river bottoms. The mining on the land is done in open trenches. The area to be mined has to be ditched in order to drain it before mining operations can be begun. Sometimes it is necessary to build embankments, to prevent the diggings from being flooded in stormy weather. At the Bolton mine, on Stono River, high tides sometimes rise two feet above the level of the land. Drainage is, in some mines, hastened by the use of steam pumps. It does not usually pay, unless the phosphate is of extraordinary quality, to remove more than eight or nine feet of overlying earth. The Pacific Guano Company, however, has lately introduced the use of a steam excavator to dig the nodules, and it is supposed that work can be profitably carried on at a greater depth with this machine than with pick and shovel.

The phosphate is carried on cars, generally drawn by an engine, from the mines to the washers. Here it is broken by machinery into coarse fragments not larger than about five inches in diameter, and then passed into the washers, where it is freed from the adhering sand and clay. Several different kinds of washers are used. The most common one is a long trough, in which revolves a shaft armed with a projection in the form of a broken helix. The trough is inclined at a small angle. The nodules are passed from the breakers to the lower end of the trough and are forced up the inclined plane by the revolving shaft against a strong stream of water. Sometimes the phosphate is washed in a revolving cylinder perforated with holes and supplied on the inside with spiral flanges of steel. A stream of water is thrown into the cylinder through an iron pipe. After passing through the washers the nodules fall on an iron screen, which separates the large masses from the smaller pieces. Sometimes two or three screens having different-sized meshes are used. The small-sized product is of lower grade than the large, as it is mixed with numerous siliceous pebbles which have gone through the screen with it.

The next step is to dry the nodules. This is done either by burning them with wood in large sheds, which sometimes hold several thousand tons, or by passing hot air through the mass. Sometimes the nodules are treated with fire and hot air combined. In this way they are freed from the 12 to 18 per cent. of moisture which they contained after being washed and are ready for shipment. On cooling, the nodules absorb about 1 per cent. of moisture, and such is their porosity that they can be made to absorb 5 to 15 per cent. of water.[1] The drying of the nodules takes 35 to 40 cords of wood for 1,000 tons of nodules, and the process lasts thirty-six to forty hours. The drying and burning of the phosphate not only save the freight on the water which it originally contained, but also make it better fitted for manufacturing purposes.

The nodules in the river bottoms are now obtained by dredging boats, though, a few years ago, large quantities were obtained by negro divers and with oyster tongs. The dredging scoops have to be very strongly built in order to break through the nodular stratum. The boats are held in position at the four corners by what are called "spuds." These are strong square poles with iron points. They are dropped into the water before dredging is begun, and go through the nodule stratum and down into the bed below, thus affording a firm support to the boat. The nodules are thrown from the scoop into the washer, which is on a lighter alongside the dredging boat. The washer, in some cases, is the same as those used by the land-mining companies; but often it consists of a truncated cone, with perforated sides, revolving on a horizontal axis. It is supplied on the inside with steel spirals, arranged around the side like the grooves in a rifle. Into both ends of the cone heavy streams of water flow. The nodules are dumped by the dredge into the small end of the cone and come out at the large end. They are then removed by a derrick to another lighter and towed to shore.

Besides the ordinary dredging machine, several other contrivances are used for raising phosphate from river bottoms. The owners of the Sea Island Chemical Works, instead of using the ordinary dredging scoop, have a contrivance consisting of six large claws which open when they descend, and close, forming a kind of bucket, when they rise. It is said that one of the machines which this company owns can dredge in 50 to 60 feet of water, while the ordinary dredging boat cannot raise the phosphate in over 20 feet of water. Another dredge has been lately introduced by Mr. Brotherhood and is known as the Broth-

[1] Dr. C. U. Shepard, jr.: South Carolina Phosphates, 1880.

erhood dredge. It consists of a revolving chain of thirty-two buckets, and is very similar to the dredge used to deepen the channel of the St. Lawrence River some years ago.

The deposits of South Carolina, though of low grade compared with some others, are now more generally used than any other known phosphate. The output of the mines, which is yearly increasing, is shipped to the North, South, and East by sea and to the West by rail. This popularity is due, not only to the cheapness of the phosphate ($5 to $6 per ton in 1886), but to the many good qualities of the low-grade acid phosphate made from it. The fact that the nodule bed extends, at an accessible depth, over many miles of country, the easy approach for large vessels up to the very mines, the abundance of water, fuel, and labor, and a climate that permits mining operations to be carried on throughout the whole year, all combine to make the South Carolina phosphates the cheapest and consequently the most productive source of supply of this material.

The mode of formation of the South Carolina nodules has been a matter of considerable dispute. Professor Holmes thinks that the surface of the Eocene marl was worn, by the action of boring animals and of erosion, into numerous lumps and balls. These, with bones of sea animals, were washed upon the seashore and, as the coastline began to rise, were collected into salt-water lagoons and swamps. Numerous quadrupeds came to lick the salt, and deposited their fæces and often died here. Hence the presence of bones of land and sea animals in the phosphate beds. The phosphoric acid in the fæces and carcasses of these animals phosphatized the lumps of marl and thus formed the phosphatic nodules.

Prof. N. S. Shaler thinks that the nodules, in some cases, have been formed by concretionary and segregating action at the bottom of swamps. Many facts, such as the frequent occurrence of phosphatic nodules in patches, and often in concave basins, as in Russia, as well as their association with peaty beds, as in North Carolina, seem, in many cases, to strongly favor this theory. Phosphatic nodules have also been found at the bottom of beds of limonite in the Ohio Valley. Professor Shaler thinks that the nodules were scattered sparingly in the deposit in which they were formed and that they were concentrated in their present position by the erosion of the original bed.[1]

Analyses of South Carolina rock phosphates, by Dr. C. U. Shepard, jr., in South Carolina Phosphates, Charleston, 1880.

An average of several hundred analyses gave:

	Per cent.
Phosphoric acid	25 to 28
Equivalent to bone phosphate of lime	55 to 61
Carbonic acid	2.5 to 5
Equivalent to carbonate of lime	5 to 11

[1] Proc. Boston Soc. Nat. Hist., vol. 13, 1869–'70, p. 222.

	Per cent.
Sulphuric acid	0.5 to 2
Lime	35.0 to 42
Magnesia	Trace to 2
Alumina	Trace to 2
Sesquioxide of iron	1.0 to 4
Fluorine	1.0 to 2
Sand and silica	4.0 to 12
Organic matter and combined water	2.0 to 6
Moisture	0.5 to 4

Table of analyses of South Carolina rock phosphates by Dr. C. U. Shepard, jr.

	Stono River light-colored nodule.	Stono River dark-colored nodule.	Stono River nodule.	Ashley River land nodule, dried.	Cooper River land deposit.	Chisholm's Island nodule, dried.	Bull River nodule, dried.	Coosaw River nodule, dried.	Coosaw River nodule, dried.
Moisture	3.68	......	1.50	0.00	.10	0.84	0.79	0.57	0.66
Organic matter and combined water	4.78	......	5.59	5.26	.07	4.22	5.80	4.31	3.75
Carbonic acid	4.68	4.28	3.89	4.47	3.55	3.54	3.61	3.79	4.34
Equal in carbonate of lime to	10.69	9.73	8.84	10.04	8.06	8.04	8.19	8.61	9.84
Phosphoric acid	25.61	26.68	25.75	27.01	27.11	27.26	25.14	27.26	26.78
Equivalent in bone phosphate to	55.91	58.24	56.21	58.95	59.18	59.50	54.88	59.51	58.46
Sand	11.55	12.41	11.77	11.37	15.39	9.06	13.30	9.06	11.77

Analysis of South Carolina rock phosphate from Oak Point Mine, by Dr. C. U. Shepard, jr.

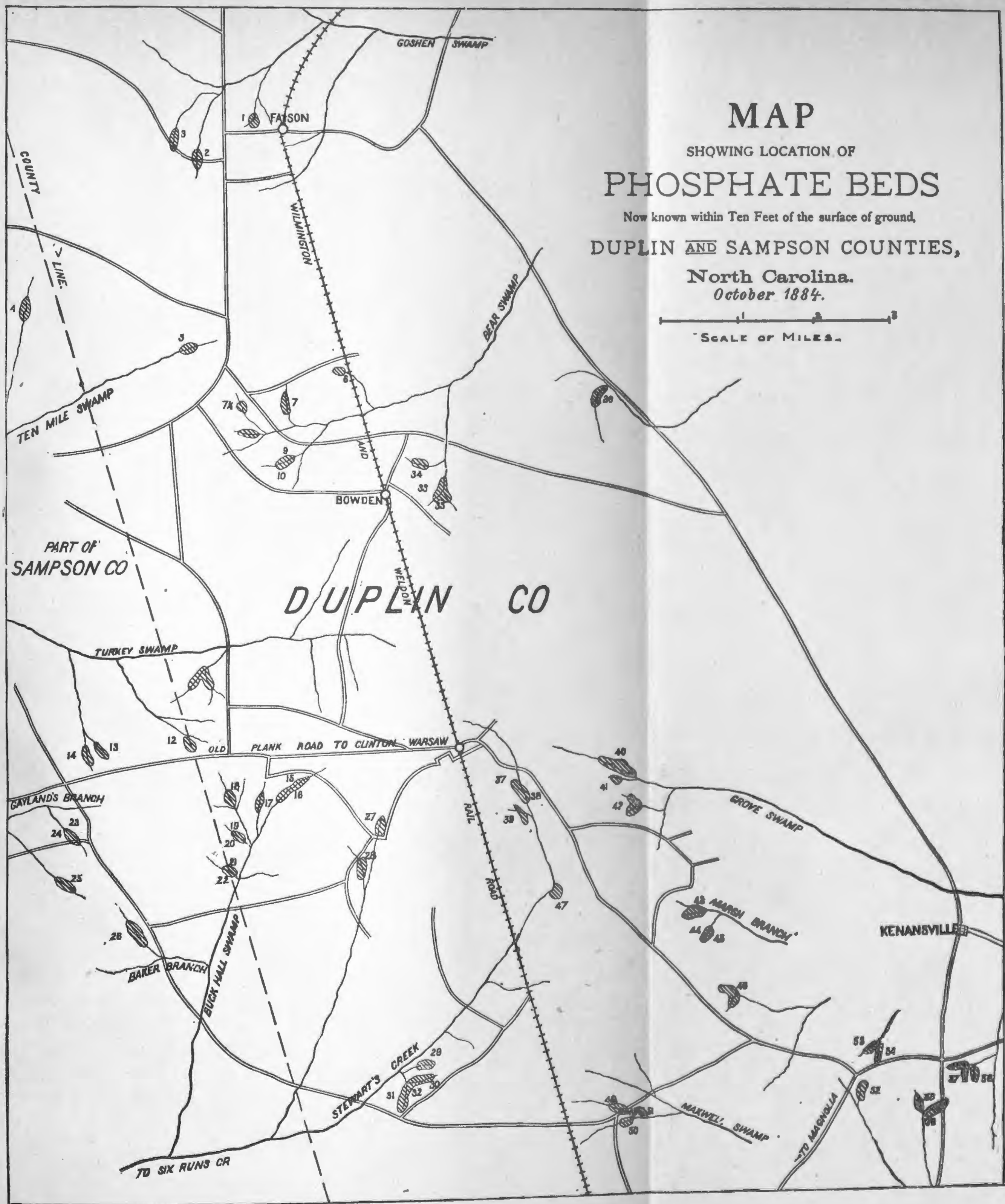
Bone phosphate of lime	58.66
Carbonate of lime	6.90

Analysis of phosphatic nodules from Bulow mine, property of William L. Bradley, by R. A. F. Penrose, jr.

Bone phosphate of lime	62.039
Carbonate of lime	6.914
Organic matter and moisture	5.106

AMORPHOUS NODULAR PHOSPHATES OF NORTH CAROLINA.

Deposits of phosphate of lime have been known to exist in the flat country near the coast of North Carolina for several years, but not much attention was paid to them until 1884, when, under the direction of Dr. Dabney, of the agricultural station of that State, they were thoroughly examined. The result seemed to show that the phosphates were either too scanty in quantity or too poor in quality to be of much commercial importance. They are found in the southeastern part of North Carolina, and principally in the counties of Sampson, Duplin, Pender, Onslow, Columbus, and New Hanover.


MAP
SHOWING LOCATION OF
PHOSPHATE BEDS
Now known within Ten Feet of the surface of ground,
DUPLIN AND SAMPSON COUNTIES,
North Carolina.
October 1884.
SCALE OF MILES.
GOSHEN SWAMP
FAISON
COUNTY LINE
WILMINGTON AND WELDON RAIL ROAD
BEAR SWAMP
TEN MILE SWAMP
BOWDEN
PART OF SAMPSON CO
DUPLIN CO
TURKEY SWAMP
OLD PLANK ROAD TO CLINTON
WARSAW
GAYLAND'S BRANCH
GROVE SWAMP
MARSH BRANCH
KENANSVILLE
BAKER BRANCH
BUCK HALL SWAMP
STEWART'S CREEK
MAXWELL SWAMP
TO MAGNOLIA
TO SIX RUNS CR

The deposits are of two kinds: (1) Beds of nodules, resembling very much the South Carolina beds and (2) a conglomerate in which the pebbles are phosphate and the matrix a white calcareous rock.

(1) The beds of nodules overlie the Eocene marl and consist of numerous phosphatic nodules, shark teeth and bones, associated in a sandy matrix or in a shell marl. Generally, the bed immediately overlies a stratum of shell marl and is occasionally overlaid by a similar stratum. Sometimes the underlying bed is replaced by a deposit of a pale-green, indurated sand, containing shark teeth and other bones. The two following sections will show the mode of occurrence of these phosphates:

1. Soil, sand or clay, 5 to 10 feet.
2. Shell marl, 5 to 10 feet.
3. Bed bearing phosphate nodules, 1 to 3 feet.
4. Sea-green, sandy marl, 2 to 4 feet.
5. Ferruginous hard pan, 6 to 12 inches.
6. Interstratified lignites and same sands as in 4.

The above section was obtained in a canal on the land of Mr. N. Daniel, Sampson County. Fragments of lignite are sometimes associated with the nodules.

Section 2, from the beds on J. W. Best's farm, Duplin County.

1. Sandy soil, 1 to 10 feet.
2. Nodule bed, 1 to 2 feet.
3. Shell marl.

The nodules are of a lead-gray color and vary from lumps the size of a man's fist to masses weighing several hundred pounds. The average size is larger than that of the South Carolina nodules. They vary in composition from the close, compact, and homogeneous masses found in some places in Onslow County, to the coarse-grained and highly siliceous rock of Sampson and Duplin Counties. The latter variety contains considerable quantities of sand, which can be distinguished with the naked eye, and occasionally siliceous pebbles the size of a chestnut. In fact, the nodules are often a phosphatic sandstone, in which the grains of sand are cemented by phosphatic matter. Occasionally they are found containing numerous Tertiary shells. Many shells are also found mixed with the nodules in the sandy matrix, and they preserve their most delicate outlines in a state of great perfection, while the nodules are much rolled and rounded. These facts would seem to show that the shells were brought into their present position by the animals that once inhabited them after the bed of nodules had been formed. A similar condition has been observed in the English beds of phosphate nodules. The North Carolina nodules are much bored by mollusks and in every respect resemble those from the Russian Cretaceous formation.

The nodules all tend toward flat shapes, in which they differ from those of South Carolina, which have no definite form. One specimen found measured 18 inches long 12 wide and 2 thick. This flat character would seem to favor the idea that the nodules were formed by the phosphatization of the surface of a bed of sandy marl. The phosphate, having a tendency to segregate, formed in some places richer than in others. Then, when the bed was exposed to erosion, only the parts which were strongly enough cemented together survived. Often, around the siliceous pebbles in a nodule, concentric bands of phosphate of lime may be observed, showing its strong tendency to form in segregations.

These deposits have not as yet been put to any commercial use. They are of a low grade, averaging only about 45 per cent. phosphate of lime, and occur only in small patches of from one to twelve acres.

(2) The second variety of phosphate deposits found in North Carolina belongs to the class of phosphatic conglomerates. They are found in New Hanover and Pender Counties and consist of a mass of Tertiary shark teeth, bones, nodules, and quartz pebbles, all well rolled and rounded and cemented together, along with grains of greensand, in a calcareous matrix. At Castle Hayne, New Hanover County, they occur in a bed sometimes over six feet deep. The largest pebbles and nodules are nearest the top of the formation and never exceed the size of a horse-chestnut. They grow smaller with the depth, and at six feet they are not larger than an apple seed. The character of the whole mass of the deposit also varies very much with the depth. The top of the bed is a hard and solid rock, but at two feet it begins to get softer, and at three to four feet the conglomerate bed is simply a mass of loose, calcareous marl containing pebbles. The section below, from near Castle Hayne, N. C., will show the nature of this bed.

1. White sand 0 to 3 feet.
2. Brown to red, ferruginous, sandy clay or clayey sand, 1 to 3 feet.
3. Green clay, 6 to 12 inches.
4. Dark-brown, indurated peat, 3 to 12 inches.
5. White, calcareous marl, 0 to 2 feet.
6. White shell rock, 0 to 14 inches.
7. Phosphatic conglomerate rock, 1 to 3 feet.
8. Gray marl containing smaller nodules than the overlying bed, 2½ to 4½ feet.
9. Light-colored, calcareous marl, containing nodules which are smaller than those in the overlying beds and which grow fewer and smaller at a depth. Many shells.

The line between the shell rock (6) and the conglomerate bed (7) is very sharply drawn. There are occasionally a few nodules found in the shell rock near the line of contact, which may have been derived from the conglomerate. The surfaces of all the beds are very uneven, especially that of the calcareous marl in the above section, which occurs only in patches on top of the shell rock (Fig. 30).

Near Wilmington, N. C., the following section was obtained:

1. Sandy soil, 2 feet.
2. Greensand bearing a few phosphatic nodules about the size of a pea, 4 feet.
3. Gray marl, 6 feet.
4. Limestone rock bearing a variable amount of nodules, of the same size as near Castle Hayne.

The nodules in 4 sometimes make up as much as three-fourths of the contents of the bed; at others they occur scatteringly through the rock, and occasionally are not found at all. They are kidney and egg shaped and generally much less bored and irregular than the South Carolina nodules. They vary from gray to greenish black in color and have a specific gravity of 2.6 to 2.7.

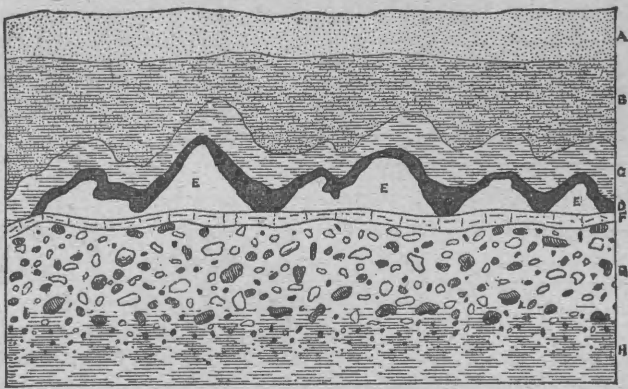


FIG. 30. Strata overlying the phosphate bed at Castle Hayne, New Hanover County, North Carolina. A, sand; B, ferruginous, sandy clay; C, green clay; D, indurated peat; E, calcareous marl; F, white shell rock; G, phosphate conglomerate; H, marl containing smaller nodules. Scale: 1 inch = 5 feet.

Two companies have been formed to grind this conglomerate rock and sell it for local use. The whole mass does not contain more than 10 to 20 per cent. phosphate of lime, but it is said to have been successfully used as a fertilizer. The separate nodules are very variable in composition.

Table of analyses of North Carolina rock phosphates made at the North Carolina experiment station.

[I to XI. From neighborhood of Warsaw, Duplin County.]

	I.	II.	III.	IV.	V.	VI.	VII.
Moisture	0.92	1.57	1.08	1.79	1.73	1.06	0.63
Samples dried at 212 degrees F. contain sand and insoluble matter	38.09	28.92	42.96	5.17	59.47	29.46	37.36
Carbonate of lime	3.81	2.43	4.18	5.91	3.12	54.89	4.96
Phosphate of lime	45.16	57.18	42.46	37.28	28.19	3.90	44.51
Equivalent to phosphoric acid	20.10	26.19	19.45	17.07	12.91	25.15	20.39

	VIII.	IX.	X.	XI.
Moisture	0.66	0.39	....	....
Sand and insoluble matter	30.44	36.59	45.62	44.73
Carbonate of lime	6.30	6.30	4.59	2.30
Phosphate of lime	53.03	45.78	39.86	39.33
Equivalent to phosphoric acid	24.29	20.97	18.26	18.01

Table of analyses of North Carolina rock phosphates etc.—Continued.

[XII to XVI. From neighborhood of N. A. Faison's, Duplin County.]

	XII. White compact.	XIII. Gray compact.	XIV. White gritty.	XV. Gray.	XVI. Common black.
Moisture	2 07	2.50	0.77	2.70	0.81
Sand and insoluble matter	1.49	0.05	32.79	0.64	45.91
Carbonate of lime	12.00	8.98	1.45	7.07	5.84
Bone phosphate	71.82	76.82	7.42	76.54	36.02
Equivalent to phosphoric acid	32.90	35.19	3.40	35.06	16.50

[I to XV. Nodules from Sampson County, N. C.]

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Sand and insoluble	47.18	47.41	70.78	54.96	1.58	51.75	32.16	44.99
Carbonate of lime	5.91	5.27	4.20	3.91	9.55	4.52	3.91	5.25
Bone phosphate	28.09	38.31	20.24	32.05	69.55	32.53	50.73	37.70

	IX.	X.	XI.	XII.	XIII.	XIV.	XV.
Sand and insoluble	36.04	52.53	49.34	29.41	51.93	50.42	53.43
Carbonate of lime	4.71	5.68	4.66	5.68	6.43	1.86	6.43
Bone phosphate	44.82	32.22	33.62	38.09	29.93	35.52	29.47

[I to II. Nodules from Pender County, N. C.]

	I.	II.
Sand and insoluble matter	61.96	24.77
Carbonate of lime	4.32	15.55
Bone phosphate	21.02	47.50

[I. Nodules from phosphatic conglomerate from New Hanover County, N. C.]

	I.
Sand	43.66
Carbonate of lime	34.56
Magnesia	0.86
Potash	0.39
Oxide of iron and alumina	0.56
Phosphate of lime	19.99
Sulphuric acid	Trace
Chlorine	Trace
	100.02

[II to VIII. Nodules from phosphatic conglomerate from New Hanover County, N. C.]

	II.	III.	IV.	V.	VI.	VII.	VIII.
Sand and insoluble matter	22.07	33.52	....	18.50	20.02	3.25	31.66
Carbonate of lime	42.12	20.45	....	39.04	42.12	51.34	15.94
Phosphate of lime	20.50	33.97	30.90	25.34	22.68	31.59	42.09
Equivalent to phosphoric acid	9.39	15.57	14.16	11.61	10.39	14.57	19.28

Table of analyses of North Carolina rock phosphates etc.—Continued.

[I to IV. Phosphatic conglomerate of New Hanover County, N. C.]

	I.	II.	III.	IV.
Sand and insoluble matter	20.28	24.96	42.98	35.48
Carbonate of lime	57.29	54.71	10.12	51.81
Phosphate of lime	11.81	16.42	26.64	6.40
Equivalent to phosphoric acid	5.41	....	12.57	2.83

[I. Phosphate conglomerate from New Hanover County, N. C.]

Carbonate of lime	64.26
Phosphate of lime	11.16
Equivalent to phosphoric acid, 5.11.	
Magnesia	0.81
Potash	0.40
Sulphates and chlorides	Trace
Sand, soluble silica, oxide of iron, alumina, etc., undetermined	23.37
	100.00

AMORPHOUS NODULAR PHOSPHATES OF ALABAMA.

The phosphate deposits of Alabama belong to the Cretaceous formation and are found in two parallel belts running across the State. The following very general section, in an ascending order, will show their positions:

(1) Eutaw group.
(2) Phosphate stratum.
(3) Rotten limestone formation.
(4) Phosphate stratum.
(5) Ripley group.

The Cretaceous formation of Alabama probably corresponds to the Upper Chalk of Europe, which also, in some places, contains beds of phosphatic nodules. It runs from the western part of Georgia in a WNW. direction through Alabama into Mississippi, where it takes an abrupt curve to the north. After passing through the western and northern part of Mississippi it enters Tennessee and runs through that State almost to the Kentucky boundary line. The phosphate deposits, it is said, can be traced along a considerable length of this formation, but, as far as has yet been discovered, it is only in Alabama, and there only in a few places, that the deposits are of considerable extent. In that State the Cretaceous strata dip gently to the south, and as a result of this dip the nodule bed, at the base of the Rotten Limestone, is found at ten to twenty miles north of the one at the summit of that formation.

The general character of the two deposits is very much the same. They are composed of shells, phosphatic nodules, shell casts, and fossils, all much worn, broken, and rounded, and buried in a matrix of a soft, white or gray limestone. The nodules are generally flat in their general shape and chestnut brown in color, and average, in size, from one-half an inch to three inches in diameter. They are very irregular in form and occasionally show one side which is completely phosphatized and another which is composed largely of carbonate of lime. This is strong evidence for the theory of their formation by the phosphatization of the surface of a calcareous bed, as mentioned in the case of the North Carolina deposits. The fossils of the two beds differ considerably. Ammonites are very plentiful in both, but *Hippurites* and *Baculites* were found in much larger quantities in the lower bed than in the upper one. The following two sections will show the different relations of the two beds:

(*a*) Upper bed (at Coatopa):

1. Greensand containing nodules and shell casts, but numerous only at the base; 4 feet.
2. Soft, calcareous rock containing nodules, 1 foot to 1½ feet.
3. Rotten limestone.

(*b*) Lower bed (at Hamburg):

1. Greensand bearing some casts and nodules, 0 to 5 feet.
2. Gray limestone containing many nodules, 5 feet.
3. Hard, indurated sand ledge, containing shells, 8 to 12 inches.
4. Yellow sand containing shells, 2 feet.
5. Ferruginous sand containing specks of mica, about 30 feet.
6. Indurated sand ledge containing shells 8 to 12 inches.
7. Yellow sand containing shells, 2 feet.
8. Greensand.

The section of the upper bed is well seen at the town of Coatopa, in Sumter County. The Greensand here is often oxidized and has a rusty-red appearance; it composes a large part of the surface soil in the neighborhood and forms part of the so-called "Black Belt," famous for its fertility. It contains many phosphatic shell casts, but is generally richest in them near the line of contact with the underlying bed, where they sometimes make up 50 per cent. of the whole mass. Occasionally they cover the whole surface of the ground and must be carted away in order to permit agricultural operations. The underlying bed contains many more nodules and shell casts than the Greensand. Sometimes it is almost a solid mass of them with a soft, gray, calcareous matrix. The bed is from 1 foot to 1½ feet thick and seems to underlie a large extent of country. In some places the nodules and fossils are more scattered in the bed than in others, and in still other places the bed has been entirely eroded away and the Greensand comes into direct contact with the Rotten Limestone. Very few bones were found in this upper bed.

Outcrops of this same nodule bed can be seen near the Tombigbee River, at Moscow, and also at Livingston, on the Sucarnochee River. In the underlying Rotten Limestone there are no phosphatic nodules.

The section of the lower nodule bed is seen at numerous places all across the State. Thus it is found at Eutaw, Selma, Greenborough, Prattville, Wetumpka, and especially well at Hamburg, near Marion.

In this last place the surface is largely composed of greensand, though, in some places, this is washed off, exposing the phosphate-bearing bed. Where the ground has been much eroded and cut into gullies, it is covered by a solid sheet of nodules, phosphatized shell casts, fossils, ferruginous concretions, and unaltered shells. There is a much larger per cent. of the brown nodules here than in the upper nodule bed; but as in that bed, so here, the nodules are very few compared with the fossils and shell casts. The indurated ledge represented in the section seems to have the same general composition as the sand that underlies it, but to be in a hardened condition.

The phosphate deposits of Alabama are more difficult to mine than the South Carolina phosphates and cannot be shipped as cheaply. Consequently they have not as yet been put to any practical use. But they have been found in sufficient quantities in several places to become of considerable local importance. Among other places, they are found in considerable quantities on the land of Mr. J. F. Wiatt, near Coatopa, and of Mr. Spencer and Messrs. Davis, near Hamburg.

Table of analyses of amorphous nodular phosphates of Alabama.

[Northern belt. (*a*) The nodules and phosphatic casts of fossils from Spencer's field, Hamburg, Ala.]

	Phosphoric acid.	Bone phosphate.	Analyist.
Nodule	22.00	48.00	W. I. Herzberg, University of Alabama.
Phosphatized shell	19.80	43.16	Do.
Surface nodules	38.00	82.84	John Daniel, University of Alabama.
Surface nodules	35.5	77.39	Do.
Surface nodules, sample 1 pound	25.66	55.88	Charles Gibson, Chicago.
Nodules from near Selma	26.1	56.90	John Daniel, University of Alabama.
Nodules from near Selma	25.8	56.24	Do.
Nodules from near Selma	36.0	78.48	Do.
Nodules from near Selma	38.0	82.84	Do.

[(*b*) Matrix of the nodules from Spencer's field, Hamburg, Ala.]

	Phosphoric acid.	Bone phosphate.	Analyist.
Matrix of nodules	5.12	11.16	E. M. Harris, University of Alabama.
Matrix of nodules	1.2	9.16	John Daniel, University of Alabama.
Matrix of nodules	4.65	10.14	L. L. Dean, University of Alabama.
Matrix of nodules	8.00	17.44	Do.
Blue matrix of nodules	2.2	4.80	Charles Gibson, Chicago.
White matrix of nodules	3.6	7.85	Do.

Table of analyses of amorphous nodular phosphates of Alabama—Continued.

[II. Southern belt. (Bulletin No. 5 of the department of agriculture of Alabama.)]

	Insoluble matter.	Phosphoric acid.	Bone phosphate.
Nodules from near Livingstone	8.48	1.10	2.40
Nodules from near Livingstone	15.02	.64	1.39
Shell casts and nodules from near Coatopa	9.38	14.56	31.78
Shell casts from Moscow	25.52	1.55	3.38

AMORPHOUS NODULAR PHOSPHATES OF MARTHA'S VINEYARD.

The phosphates of Martha's Vineyard occur as black or dark-gray nodules, varying from one-fourth of an inch to four inches in diameter, in two beds of Greensand. The beds are of Tertiary age and are well seen in the cliffs at Gay Head. They are each 18 to 24 inches thick and dip at an almost vertical angle. They are associated with beds of lignite, clay, and sand. The nodules are mixed with numerous bones of cetaceans, crustacean remains, and other fossils. The more southerly of the two beds contains 5 to 15 per cent. of nodules and bones, while the bed to the north contains in some places almost no nodules, and in others as much as 25 per cent. of them. The nodules have a water-worn appearance and have been much bored by marine mollusks. They give off a smell of decayed organic matter when two fragments are rubbed together, and have a hardness of about 3.

This deposit has not yet been put to any practical use. The nodules are probably too scattered in the bed and too expensive to mine to allow them to be of any commercial value.[1]

AMORPHOUS NODULAR PHOSPHATES OF FLORIDA.

Phosphate deposits have been found in various places in Florida, but as far as is yet known they are either of too small extent or of too poor quality to pay for mining. The only deposit which covers more than a few acres is found in Alachua County, near the central part of the State. The phosphate found here belongs to the subdivision of phosphatic conglomerates. The rock consists of small pebbles, from the size of a mustard seed to that of a pea, closely packed in a matrix of indurated calcareous marl. The pebbles are very compact, have a small conchoidal fracture and sometimes an enamel-like luster. They are creamy white to chestnut brown in color and are associated with

[1] It seems to me certain that these beds containing nodules were deposited in the delta of a large river and that the nodules, together with the greater part of the fossils with which they are intermingled, were derived from pre-existing strata in essentially the same manner as those which occur in the estuaries of the rivers near Charleston, S. C.

For a further description of these deposits see a report on the island of Martha's Vineyard, now in press, to appear in the Seventh Annual Report of the U. S. Geological Survey.—N. S. S.

worn and rounded bones and shells. Prof. C. U. Shepard, sr., thinks that many of the pebbles may be the worn casts of marine shells, while some of them seem to be fragments of coral. This conglomerate occurs in masses weighing from one to twenty pounds. The largest mass yet found was 18 inches long, 14 wide, and 4 thick. The pebbles occur in a bed covering about ten acres and are associated with pieces of a porous limestone rock, very common in the region. The bed varies from a fraction of a foot to five feet in thickness. Sometimes it crops out at the surface, and at others it is found at a depth of four or more feet. At Gainesville, a town 19 miles west of this bed, a similar rock is said to have been found, in boring an artesian well, at a depth of 248 feet.

The masses of rock are not nodules, but seem to be simply broken fragments. They are much weathered and rounded and are buried in sand.

In some places the pebbles, rounded bones, and coral fragments occur loose in a calcareous matrix, as if weathered out of the original conglomerate. Samples of pebbles from this loose material are said by one of the owners of this place (Dr. Simmons) to average 85 per cent. phosphate of lime, while the whole mass of the rock, as analyzed by C. U. Shepard, jr., averages about 48 per cent.

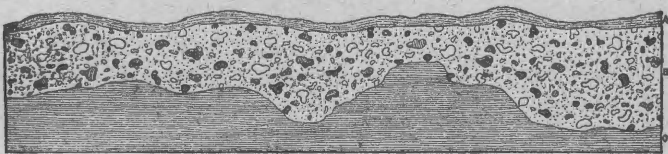


FIG. 31. Section in quarry at Rocky Hill, on Lochloosa Creek, near Magnesia Springs, Alachua County, Fla. A, sandy soil; B, calcareous nodules, white, brown, and purple, embedded in sand; C, spongy, calcareous rock, blending at a depth of 3 to 4 feet into a phosphatic rock. Scale: 1 inch = 8 feet.

On the northwest side of this bed runs a stream known as Lochloosa Creek, beyond which is a ridge rising sixty to seventy-five feet above the creek, and called Rocky Hill. The hill is overlaid almost entirely by a deposit of calcareous stones and pebbles, embedded in sand, which sometimes entirely runs out, and again reaches a depth of over six feet. Below is a soft, porous, calcareous rock, which is of a spongy consistency and hardens on exposure to air. It is quarried for building the chimneys and foundations of houses. In one of the quarries examined this formation gradually blended, at a depth of three to four feet, into a massive and compact phosphate rock, which is similar in appearance to the phosphatic fragments in the bed described above, except that it is in a solid mass, and is probably the ledge whence the fragments were derived. The surface of the spongy, calcareous rock is very uneven and has been much eroded (Fig. 31). It seems as if Rocky Hill, when submerged, was much worn before the pebbles and the sand were deposited on top of it.

AMORPHOUS NODULAR PHOSPHATE DEPOSITS OF NORTH WALES.

The rock phosphate deposits of North Wales belong to the Caradoc and Bala group of the Cambro-Silurian or Lower Silurian formation. They immediately overlie the Bala limestone beds and are overlaid by fossiliferous shales, sometimes more or less calcareous. They belong to the class of rock phosphates, or phosphates having no definite chemical composition, and are remarkable as being, geologically, the oldest of the commercially important phosphate beds which still preserve the remains of organic life.

The phosphate bed has been traced by Mr. D. C. Davies from the town of Llanfyllin to the hills north and west of Dinas Mowddwy.[1] Mr. Davies has calculated that the area already known to contain this bed amounts to almost 140 square miles, and he thinks it will probably be found wherever the Bala limestone occurs.

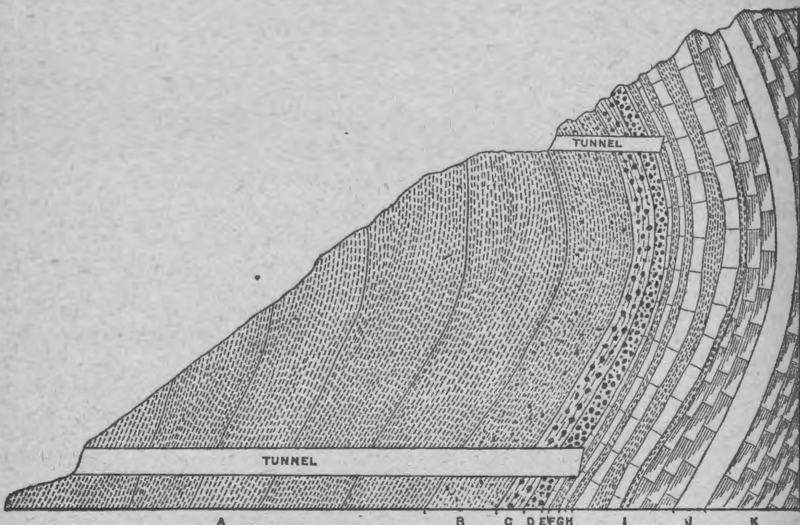


FIG. 32. Section of strata at Cwmgwynen phosphate mine, southwest of Llangynog, North Wales; after D. C. Davies, Quarterly Journal Geological Society of London, 1875. Scale: 1 inch = 80 feet.

As will be seen from the sections (Figs. 32 and 33), the formation in which the phosphate bed occurs has been much twisted and contorted. In fact, the phosphate bed, wherever found, is in an almost vertical position. It varies from ten to fifteen inches in thickness and consists of a mass of black nodules, varying from the size of an egg to that of a cocoanut, "closely packed together and even running into each other." The nodules are cemented into a solid mass by a black matrix, and the whole mass gives an average of 46 per cent. phosphate of lime, while the separate nodules sometimes contain 64 per cent. The bed contains considerable graphite, which gives the black color to both the nodules and the matrix and often gives the former a polished and glossy ap-

[1] Geol. Mag., vol. 2, London, 1875, p. 183.

pearance. There are numerous remains of animal life in the bed, but the whole deposit has been so affected by chemical action that, though the traces of organic forms are left, it is often very difficult to distinguish them. Still Davies[1] has recognized the remains of *Modiola*, *Aviculopecten*, *Orthoceras*, *Orthis*, *Lingula*, and trilobites, besides traces of many other species.

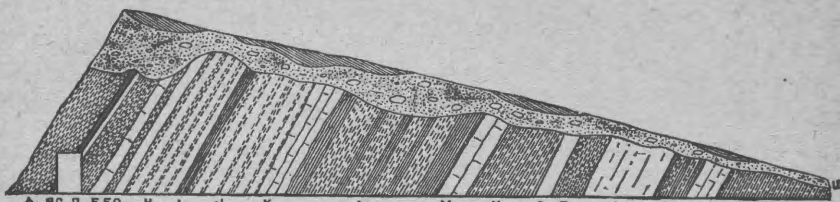


FIG. 33. Section of strata at Berwyn phosphorite mine, west of Llangynog, North Wales; after D C. Davies, Geological Magazine, London, 1875. Scale: 1 inch=32 feet.

M. H. Johnson,[2] who has made numerous sections of the North Wales nodules, has found that many of them contain a species of sponge. He has also found in the nodules fragments of mollusk and crustacean shells, with bodies looking like *Coscinopora*. From these observations he concludes that the nodules are of organic structure. It seems more likely, however, that the nodules resulted from the phosphatization of a calcareous bed, which may have contained the organic remains discovered by Mr. Johnson in the nodules. Davies thinks the bed represents the remains of an old Laminarian zone and that it originated by the phosphatization of calcareous matter by the phosphates from animal matter and seaweed.

The nodules have been so affected by heat and chemical action that they often are found blending and running into each other. They sometimes blend gradually with the matrix, the whole bed assuming a shaly structure, so that it is often impossible to draw a distinct line of division. The mass of the stratum is sometimes found to have a very similar composition over large areas; but where the underlying bed becomes more arenaceous the nodules become much poorer in phosphate and richer in siliceous matter.[3] Thus, at Green Park, the bed averages only 20 per cent. phosphate of lime. The phosphate stratum, in some places, contains numerous concretions and crystals of sulphide of iron, which rust on exposure to the atmosphere, thus changing the color of the bed from black to brown. The phosphate of lime is itself often replaced by these sulphides. Such is the case in many parts of the western outcrop of the bed, especially on the flanks of Mount Aran

[1] Geol. Mag., vol. 4, London, 1867, pp. 251-253.

[2] Ibid., vol. 2, n. s., 1875, p. 238.

[3] This is a strong argument for the theory of the formation of the nodules by the phosphatization of the underlying bed.

Mowddwy. Such large quantities of sulphides and graphite as are found in this phosphate bed, according to Davies, seem to show the former presence of vegetable life.

An examination of the analyses given farther on will show that there is little or no carbonate of lime in these phosphates. Davies, in speaking of this fact, says:[1]

Schmidt found in the inner side of the mouth of *Unio* and *Anodonta* no less than 15 per cent. of phosphate of lime, 3 per cent. of carbonate of lime, and 82 per cent. of organic matter, from which the inference was drawn that the phosphate was separated from the blood by this organ for the purpose of cell formation.[2] The doctor adds: "It seems probable that the carbonate is converted, in the animal, into phosphate by the phosphorus it contains." Here, perhaps, we have a clew to the missing carbonate. The great preponderance of phosphatic organisms, with which the period covered by the deposit commenced, gradually absorbed and secreted all carbonate of lime, whether held in solution in the water or redissolved from the shells of dead mollusks; and so, turning it into phosphate, grew and multiplied exceedingly, and became at last almost sole masters of the position by this appropriation, until the supply of carbonate of lime became insufficient for their sustenance, as the mineral conditions came on under which the overlying shales were deposited.

It seems possible, however, that the absence of carbonate of lime in the Wales phosphate is due to its having been leached out during the process of partial metamorphosis to which the bed has been exposed; as the effect of metamorphosis is often to segregate from the rock which is being acted on the minerals of which it is composed.

The phosphate bed is often separated into two or three smaller beds by thin bands of the underlying limestone. It is always found, however, that when the upper one or two beds, as the case may be, run into the overlying shale they always run out and the lowest bed is always the continuous one.

The bed immediately underlying the phosphate bed is a pure limestone, often covered on the surface with small brachiopods and other fossils. It has an average thickness of 6 inches and contains 15 to 20 per cent. phosphate of lime. Like the phosphate bed, it is very continuous and the two are always found together. It is underlaid by a large series of interstratified shales and more or less fossiliferous limestones. This formation, known as the Bala limestone, gradually runs into the underlying ash beds.

The phosphate bed is overlaid by a series of fossiliferous shales. Those immediately over it have all been phosphatized to a greater or less extent, and the more the phosphatization has gone on the more completely have all traces of organic life been obliterated. In the overlying shale at Cwmgwynen, Davies found remains of *Echinosphærites balticus*, *Caryocystites*, and other echinoderms, *Lingulæ*, *Modiolæ*, *Theca*

[1] Quart. Jour. Geol. Soc. London, 1875, vol. 31, pp. 364.

[2] *Unio* and *Anodonta*, as well as all other species of the suborder to which they belong, are fresh-water forms, while the beds under consideration are certainly of marine origin. It is most likely that the phosphate matter came from brachiopods and trilobites.—N. S. S.

Forbesii, Cyclocerus arcuatum, C. Sonax, Orthocerata, Illænus Davisii, and other forms.

The phosphate bed of North Wales was discovered by a miner in 1863, in a ravine near Cwmgwynen, 5 miles from the town of Llanfyllin. At first the nature and value of the bed were unknown, but finally a specimen was sent to Dr. A. Völcker, who analyzed it and made known its importance. Several mines have since been started at Cwmgwynen, Penygarnedd, Berwyn, Llanfyllin, and other places, but none of them has been successful and at present no Welsh phosphate is mined. The reasons for this want of success were the distance of the mines from any railroad or navigable river, the low percentage of phosphoric acid (see analyses), and the depressed state of the phosphate market. Moreover, the bed is expensive to work, as regular mining operations are necessary to win the phosphate; it also often contains considerable iron, which causes superphosphate made from it to have a sticky consistency.

Analyses of North Wales rock phosphates.

[I and II. Analyses of two specimens from Cwmgwynen, by Völcker (Quart. Jour. Geol. Soc. London, 1875).]

	I.	II.
Phosphate of lime	64.16	48.50

"There was no carbonate of lime, some fluoride of calcium, alumina, and oxide of iron.

"The darker-colored contained more graphite and were richer in phosphate of lime than the lighter-colored specimens."

[III. Analyses of nodule from Berwyn mine, North Wales, by D. H. Richards (ibid., vol. 31, pp 364, 365).]

Moisture and organic matter	4.200
Sand	22.600
Tribasic phosphate of lime	64.165
Oxide of iron and alumina	6.890
Other constituents not determined	2.145
	100.000

Another analysis of a similar nodule gave 61.44 per cent. phosphate of lime.

[IV and V. Analyses of Berwyn mine phosphate, North Wales, by F. C. Hills and Co. (ibid., p. 365).]

	IV.	V.
Loss on burning	6.77	3.06
Phosphoric acid (1)	22.54	20.92
Lime	31.08	30.13
Oxide of iron and carbonic acid	19.12	22.88
Insoluble matters	20.49	23.01
Total	100.00	100.00
(1) Equal to tribasic phosphate of lime	49.207	45.67

Five other analyses of the bulk of the deposit, made by Messrs. Hills, gave an average of 46.85 per cent. phosphate of lime. There was also in all the samples about one-half per cent. of copper. Analyses of phosphate from near Llanfyllin, North Wales, gave Messrs. Hills "a range of from 20 to 30 per cent. of phosphate of lime," (Quart. Jour. Geol. Soc. London, 1875, vol. 31, p. 365.)

[VI and VII. Analyses of two samples from northwest of Dinas Mowddwy and Llan-y-Mowddwy, North Wales, by Hills (Quart. Jour. Geol. Soc. London, 1875).]

	VI.	VII.
Phosphate of lime	2.90	1.72
Sulphur	34.38	34.20

The rest was made up of sand, iron, and alumina.

[VIII. Analysis of North Wales phosphatic limestone, by Völcker (Rep. Brit. Assoc. Advanc. Sci., 1865, p. 38).]

Tribasic phosphate of lime	34.92
Oxide of iron	2.34
Alumina	6.52
Carbonate of lime	20.75
Carbonate of magnesia	5.92
Magnesia, in a state of silicate	2.07
Iron pyrites	2.79
Sulphuric acid	0.16
Insoluble siliceous matter	20.95
Organic matter and loss	3.58
	100.00

[IX. Analysis of phosphatic black shale, by Völcker (ibid., p. 38).]

Organic matter and loss	3.98
Lime	37.16
Phosphoric acid	29.67
Equal to tribasic phosphate of lime, 64.16.	
Magnesia	0.14
Oxide of iron	1.07
Alumina	5.84
Matter insoluble in dilute hydrochloric acid	22.14
	100.00

[X. Analysis of phosphatic black shale, by Völcker (ibid., p. 39).]

Tribasic phosphate of lime	52.15
Lime, present as fluoride of calcium and as silicate	4.23
Magnesia	0.32
Alumina	7.71
Oxide of iron	2.01
Sulphuric acid	0.26
Iron pyrites	7.52
Insoluble siliceous matter	22.44
Organic matter and loss	3.36
	100.00

AMORPHOUS NODULAR PHOSPHATE DEPOSITS OF ENGLAND.

Phosphates are found in England, both in the Cretaceous and Tertiary formations. The Cretaceous phosphates are the most important, in both quantity and quality. They occur in two different parts of the Lower Cretaceous, namely, in the Upper and in the Lower Greensands.

Phosphatic beds of Cretaceous Upper Greensand.—The outcrop of the Upper Greensand formation in England begins in the north at Flamborough Head, in Yorkshire, and runs west and southwest for about twenty miles, when it turns abruptly to the southeast and extends continuously in that direction to within three miles of the north coast of the Wash, where it becomes covered with alluvium. It appears again on the south shore of the Wash at St. Edmunds and runs south by southwest to Downham Market. Here it becomes covered with alluvium and does not appear again for about twenty-three miles, when it crops out three miles below Cambridge, on the Cam. From Cambridge it runs in a southwesterly direction through the counties of Cambridge, Bedford, Buckingham, Oxford, Berks, Wilts, and Dorset, and reaches the southern coast at Lyme Regis and Sidmouth. On the southern coast of Dorsetshire there are numerous outcrops of Upper Greensand, as well as on the Isle of Wight. In the southeast of England there is also a very considerable Greensand outcrop. It commences near Beachy Head, in Sussex, and runs west by a little north to Petersfield, in the east of Hampshire. Here it turns abruptly to the north and runs in this direction to Alton and Farnham, in Hampshire and Surrey, respectively. Thence it takes another abrupt turn to the east, and runs in a general easterly direction until it comes to the coast again, at Folkestone in Kent.

The Lower Greensand is not so continuous as the upper, but it occurs at intervals along most of the outcrops mentioned above, and in Sussex and Kent it is the uninterrupted accompaniment of the Upper Greensand. In Yorkshire it runs from Flamborough Head west for about fifteen miles. It crops out again with the Upper Greensand about three miles south of Barton and runs continuously to Burgh. Again it crops out near Cambridge, and extends thence to Buzzard in Bedford. From there on, in a southwest direction, it occurs in small outcrops along the line of the Upper Greensand. In the Isle of Wight there are large outcrops of it. This same Greensand belt can be traced across the English Channel to the Continent. In the Brunswick and Hartz districts, at Goslar, Schoeppenstedt, and Salzgitter, the same nodules and shell casts are found as in the Lower Greensand in Cambridgeshire and Bedfordshire. But, though the belt is thus seen to have a very wide extent, the conditions which are necessary for the profitable working of a phosphate deposit are so many and so rarely satisfied that the phosphatic beds have been mined in very few places throughout this many hundred miles of outcrop. On the Continent the bed has been worked to no considerable extent.

The relative positions of the Upper and Lower Greensand formations is best shown by a section. The following one is given by Messrs. Paine and Way.[1]

The Cretaceous formation of England is divided into the Chalk and the Greensand. These again are subdivided as follows:

Chalk	1. Soft, white chalk with flints. 2. Hard, white chalk with few or no flints. 3. Chalk marl.
Greensand	1. Upper Greensand and firestone rock. 2. Gault, or blue marl. 3. Lower Greensand, made of iron sand and occasional limestone beds.

[1] Jour. Royal Agric. Soc., vol. 9, 1848.

The first two beds of the chalk are very poor in phosphoric acid, rarely containing over twelve-one-hundredths of 1 per cent., but the underlying marl is much richer and sometimes contains almost 2 per cent. of phosphoric acid. The marl is of a grayish color and contains specks of Greensand, which become more and more numerous until the marl gradually merges into the underlying Greensand bed containing the phosphatic nodules. The passage from the Upper Greensand to the Gault is often very abrupt, especially in Cambridgeshire and Bedfordshire, where the nodule bed often lies on the eroded surface of the Gault. The Lower Cretaceous deposits of Cambridgeshire and Bedfordshire differ from those of the south and west of England in the fact that the former lack that great thickness of Upper Greensand which exists in the southern counties. At the same time the lower beds of the Chalk are the same in both areas. In Hampshire and Dorsetshire there is a thin stratum, similar to the Cambridge nodule beds, which, like it, passes up gradually into the Chalk marl. But the difference is that in the case of the southern counties the arenaceous deposit, which sometimes reaches the thickness of many feet, comes between the phosphate bed and the Gault, while in the case of the Cambridge and Bedford deposits the nodule bed, which rarely exceeds one foot in thickness, rests immediately on the Gault. Concerning the absence of this arenaceous deposit in Cambridgeshire, Mr. O. Fisher[1] says: "It is probably due to the ridge of old rocks beneath the London area, which shut off the early Cretaceous sea, to the north of it, from those southwestern lands which yielded the sandy spoils." He also suspects a similar cause to have "produced the marked change between the Lower Cretaceous rocks in Cambridgeshire and the corresponding beds in Norfolk and Lincolnshire." Mr. Seeley[2] thinks that this increased thickness of Greensand to the south and southwest is due partly to the shelving of the sea bottom towards the south and partly to a current piling it up in the hollow, but principally because the southern area was nearer to the old plutonic rocks, whence, he thinks, the necessary ingredients of the Greensand came.

The principal phosphate diggings have been in the Upper Greensand of Cambridgeshire and Bedfordshire. The nodules in this deposit are buried in the Greensand, which varies from one inch to a foot in thickness and which is all that is left in these districts to represent the immense thickness of Greensand in the southern counties. In fact, it is a matter of serious doubt with some geologists whether the two deposits really represent one and the same geologic horizon.

The matrix of the nodules is not pure Greensand, but is composed partly of siliceous and calcareous matter and partly of glauconitic and phosphatic grains. The siliceous matter consists mostly of colored

[1] Quart. Jour. Geol. Soc. London, vol. 29, 1873, p. 62.
[2] Geol. Mag., vol. 3, London, 1866.

quartz, obsidian, and grit. The calcareous matter is composed mostly of sponge-spicules, spines and plates of echinoderms, minute shells, polyzoa, bivalve entomostraca, microscopic corals, foraminifers, and calcareous concretions.[1] There are also in the bed "lumps of Chalk marl[2] which have fewer green grains in them than the matrix in which they are embedded." From this and other facts Mr. Fisher concludes that these phosphate beds seem to have been washed out of a calcareous marl, similar in character to the marl which lies above it. In short, he continues, the nodule bed is a condensation of the "Chalk marl with glauconite grains." On the other hand, Mr. Sollas thinks that the nodule bed has been derived from the destruction of the underlying Gault. The Gault contains nodules and fossils, but not nearly so many as the overlying bed. Mr. Fisher urges against this hypothesis that the nodules of the Gault are smaller and of a lighter color than those of the nodule bed proper. Though the nodules are of a lighter color on the surface, the interior is of a color very similar to that of the Greensand nodules. Mr. Sollas shows that by the action of hydrochloric acid the Greensand nodules assume this same color on the surface, and consequently it is possible that the Gault nodules may have been acted on by water, acidulated by some acid or acid salt, percolating through the bed, and thus had their surfaces bleached.

The phosphatic part of the nodule bed consists of shell casts, fossils, and nodules. There are numerous species of *Rhabdospongia*, *Bonneyia*, *Acanthophora*, *Polycantha*, *Retis*, and *Hylospongia*, besides many other Cretaceous forms. The nodules and casts are of a black or dark-brown color and have a very variable specific gravity and hardness.

Many of them are worn, broken, and rounded, showing them to be clearly derivative masses, while others are perfect in shape and show no signs of having been removed from their original bed.[3] The derivative fossils and nodules are covered with *Plicatulæ*, and the smooth, broken surfaces of many of them, which are coated in this way, show, as Mr. Fisher thinks, that they must have been phosphatized before being deposited in their present bed, and he thinks that the phosphate was concentrated from a carbonic acid solution by animal matter. Besides the shell casts and fossils, there are two distinct varieties of nodules proper. The first is a reddish-brown and utterly shapeless variety. It is very soft when freshly dug, never becoming harder than ordinary chalk.[4] It has a very light specific gravity and is invariably rich in phosphoric acid.[5] A second variety is much more plentiful than the last. It consists of a dark-brown mass of a very variable shape. It is hard and heavy. It varies from pieces of micro-

[1] W. J. Sollas: Quart. Jour. Geol. Soc. London, vol. 28, 1872, p. 398.
[2] O. Fisher: ibid., vol. 29, 1873, p. 53.
[3] O. Fisher: ibid.
[4] Paine and Way: Jour. Royal Agric. Soc., 1848.
[5] See analyses.

scopic smallness to masses weighing four pounds. It occurs adhering to the surfaces of *Syphonæ*, corals, and shells, and appears to have once been in a plastic state. This substance has been called by Dr. G. A. Mantell[1] "molluskite," and he considers it the remains of the soft parts of mollusks. In describing it he says:

This substance is of a dark-brown or black color, and occurs either in shapeless masses, which are irregularly distributed among the shells and other organic remains, in sandstone, limestone, etc., or as casts of shells, or occupying their cavities. * * * Upon analysis this substance is found to contain a large proportion of animal carbon. The rocks of firestone at Southbourne, on the Sussex coast, are mottled with brown molluskite and hard amorphous concretious, consisting of carbon and phosphate of lime, mixed with sand and other extraneous matter. Casts of shells of the genera *Venus* and *Arca*, etc., entirely composed of the same kind of materials, are also abundant in those rocks. * * * The gelatinous bodies of the *Trigoniæ*, *Ostreæ*, *Rostellariæ*, *Terebratulæ*, etc., detached from their shells, may have been intermingled with the drifted wood in a sand-bank; while in some instances the animal matter would remain in the shells, be converted into molluskite, and retain the form of the original.

Both Mr. Fisher[2] and Mr. Sollas,[2] who have spent considerable time in studying the nodule bed of the Upper Greensand, concur in the belief that the nodules are not of either concretionary or coprolitic origin, but are composed of phosphatized animal matter. In this belief they agree with the theory of Dr. Mantell in its most important point.

Many of the nodules are traversed by shrinkage cracks and wrinkles and have a peculiar granulated surface like that of leather. Mr. O. Fisher says:

On the whole a microscopical examination of these bodies rather recalls me, so far, to my original opinion that they were sponges, while at the same time it must be admitted that in their external appearance they much resemble *Alcyonaria*.

It is often found that the nodules are richer in their exterior part than in the interior. Thus Professor Way found the following results in analyzing different parts of a spongoid body:[3]

Exterior	32.27 per cent. phosphate of lime. 61.71 per cent. carbonate of lime.
Intermediate	13.87 per cent. phosphate of lime. 67.14 per cent. carbonate of lime.
Interior	10.26 per cent. phosphate of lime. 67.17 per cent. carbonate of lime.

Such results have been found to hold true with many other phosphates and show, beyond a doubt, that the phosphatization went on from the outside towards the interior. As regards the internal structure of some of these nodules, Mr. Sollas says:[4]

Thin sections examined under the microscope vary from colorless to yellowish brown when transparent, but sometimes they are almost opaque from included earthy

[1] Medals of Creation, vol. 1, p. 432.
[2] Quart. Jour. Geol. Soc., vol. 29, London, 1873.
[3] Jour. Roy. Agric. Soc., 1848.
[4] Quart. Jour. Geol. Soc., vol. 29, London, 1873.

matter. Granular patches of a deep-red color are sometimes scattered throughout the lighter-colored portions. Spicules occur in many sections, presenting some of the most characteristic forms of sponge-spicules; as, for example, hexaradiate, triradiate, hamate, sinuate, and connecting forms. These spicules are frequently grouped together in a manner which seems to indicate that they cannot have been washed in from the sea bed during fossilization. Globular bodies $\frac{1}{400}$ inch in diameter are numerous; they seem to be gemmules. *Polycistina* and *Xanthidia* occur in some sections. With polarized light the sections appear distinctly cryptocrystalline, presenting an appearance very nearly resembling that of chalk flints when examined in the same way. A very curious phenomenon may be alluded to here. A number of small circles may be seen in some sections, each of which is marked by a black cross, the arms of which radiate from the center to the circumference. On turning the analyzer the cross revolves and, when the analyzer has been turned round 90°, is replaced by a complementarily illuminated cross. The explanation of these appearances seems to be as follows: Small *Globigerina* shells and other similar spaces occur in the nodules, into which the crystalline apatite, which was diffused throughout the fossil, has penetrated and crystallized inwards from their walls to their centers, thus forming a radiating mass of crystals. It is well known that crystals arranged in this way will produce the phenomena described.

Mr. Sollas[1] thinks that many of the nodules of the Upper Greensand are phosphatized sponges. Others he considers to be "phosphatized animal matter decomposed so far as to have lost all traces of its original structure before mineralization." He found fish scales and bones in many of these nodules, and therefore concludes that the animal matter was sometimes derived from small fish. He does not seem to take into consideration that the scales and bones may have been buried in a matrix of calcareous matter, and that this substance, whether it was marl or limestone, may have been phosphatized, thus forming phosphatic masses, which, of course, would contain the same fossils as the original calcareous substance from which they were formed.

The phosphate bed of the Upper Greensand varies considerably, not only in the quantity of phosphatic nodules, but also in the chemical composition of the individual nodules. It is often found that two places may be equally rich in the quantity of nodules, while the content of phosphoric acid in them may be widely different.

All through the counties of Dorset, Somerset, Wilts, and Devon the nodules are very much more siliceous and less abundant than the nodules of Cambridgeshire and Bedfordshire.[2] Besides the variability in the phosphatic richness of the bed, it is also sometimes very variable in its mode of occurrence. At times it will cover many square miles continuously, while at others it occurs in pockets in the surface of the Gault. At other times, according to Mr. Fisher, the bed shows signs of contortion, as indicated in Fig. 34. It will be seen, by examining the analyses given beyond, that the Greensand matrix of the phosphatic nodules varies also very much in its content of phosphoric acid. The

[1] Quart. Jour. Geol. Soc., vol. 28, 1872, p. 398.

[2] L. Jenyns: Geol. Mag., London, 1866.

amount varies from 2 to 10 per cent., and is probably due to small grains of phosphatic matter in it.

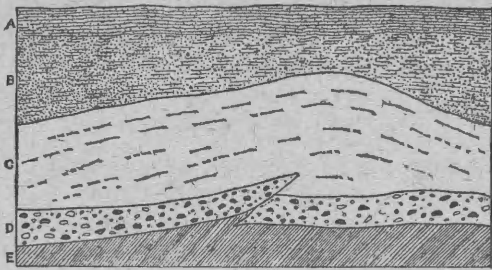


FIG. 34. Distorted bed in Cambridgeshire, England; after O. Fisher: Geological Magazine, London, 1871. A, shelly soil; B, clay or clayey gravel; C, white clay; D, phosphate nodule bed; E, Gault.

Phosphatic beds of Cretaceous Lower Greensand.—These beds occur between the Coral Rag formation at the base and the Gault on the top. Their position with regard to these formations will be best seen in Fig. 35, section at Upware, Cambridgeshire.[1] The Coral Rag is a coralline rock varying much in texture, sometimes loose and porous, and at others compact and oölitic or arenaceous. Upon this the Kimmeridge Clays rest, probably conformably.[2] But at some places, as at Upware, the Kimmeridge Clay has been washed off the Coral Rag, which, in such cases, often comes into direct contact with the overlying nodule bed. Sometimes, as a result of this destruction, there is a deposit of fragments of Coral Rag and Kimmeridge Clay immediately overlying the Coral Rag formation.

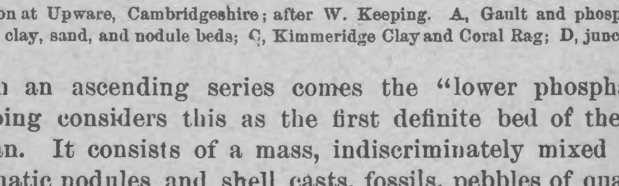


FIG. 35. Section at Upware, Cambridgeshire; after W. Keeping. A, Gault and phosphatic nodule beds; B, clay, sand, and nodule beds; C, Kimmeridge Clay and Coral Rag; D, junction bed.

Next in an ascending series comes the "lower phosphate bed." Mr. Keeping considers this as the first definite bed of the Upware Neocomian. It consists of a mass, indiscriminately mixed together, of phosphatic nodules and shell casts, fossils, pebbles of quartz, flint, Lydian stone, and jasper, besides occasionally a fragment of Coral Rag. They are all more or less rounded and worn, though some of them still preserve their angular shape. The stones and nodules vary from one-

[1] The Fossils and Palæontological Affinities of the Neocomian Deposits of Upware and Brickhill, by Walter Keeping, p. 4.

[2] Ibid., p. 3.

sixteenth to an inch in diameter and are embedded in a sandy matrix. Very often the mass has been cemented together by calcareous matter, forming irregular patches of conglomerate. There also occur in this bed many delicate and beautiful shells of mollusca, which are not at all worn, but preserve their most delicate parts intact. Lamellibranchs and gasteropods are numerous.

Above this bed comes a bed of sand composed largely of grains of ironstone, quartz, chert, and Lydian stone. Near the overlying and underlying beds there are irregular masses of slightly phosphatic sandstone.

Next above this sand bed comes the "upper phosphate bed." It resembles the "lower phosphate bed" in most respects, except that its nodules are of a lighter color, and the bed is not cemented by carbonate of lime, so that it has nowhere been indurated into a conglomerate. The siliceous pebbles are the same.

Overlying this is another bed of sand very similar to the lower sand bed.

Above this comes a clay bed. It has been referred to the Gault, but Messrs. Keeping and Bonney think that it is probably the representative of a bed of sandy clay belonging to the Lower Greensand. This is thought more likely, because phosphatic nodule beds, especially in the Cretaceous formation, usually occupy the lines of chronological breaks.

The overlying bed is another bed of phosphatic nodules. It contains many fossils and is very similar to the two nodule beds already described. This bed is overlaid by the Gault formation.

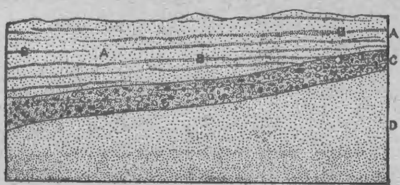


FIG. 36. Section at Sandy, Bedfordshire, England, after J. F. Walker. A, sand; B, oxide of iron C, conglomerate; D, sand.

Sometimes the three phosphate beds mentioned above seem to combine into one (Fig 36). Sometimes, also, the lower bed is not cemented, but is loose and sandy, just like the upper beds. The following sections will show the variations in the upper Neocomian deposits:

Section by W. Keeping and E. B. Tawney, at Spinney Abbey.

		Ft.	In.
A	1. Brown surface earth	1	6
	2. Head of blue clay	0	9
	3. Irregular gravelly zone, the pebbles being mostly flints and coprolites, about	0	3

		Ft.	In.
B	4. Blue, yellow, and coarsely mottled plastic clay, with scattered coarse quartz and other sand grains and numerous sandy concretions	2	0
	5. The "silt bed," a chocolate-brown and yellowish sand, passing into a sandy clay, which is rather coarse, loose, and like an ordinary shore sand. It consists principally of quartz and iron grains. This bed passes gradually into bed 4	2	0
	6. The "upper coprolite seam," a pebble bed of phosphatic nodules, Lydian stone, chert, quartz, and other pebbles as big as beans packed in loose, iron-colored sand. Some irony concretions occur in its upper part, where it passes into bed 3	2	0
	7. The "lower coprolite seam," a thin band where the coprolites are darker and better than in the upper seam. The sandy matrix is hardened almost to a rock by carbonate of lime, which was probably derived from the underlying bed (*a*)	0	3
C	A calcareous grit of coralline age. It is a hard, gritty, bedded limestone, gray colored, with scattered large oölitic grains; no fossils seen		

In the last section the nodules are darkest near the base. The phosphatic and siliceous pebbles are in about equal quantities. Silicified wood, ferruginous concretions, and hard lumps of clay are numerous. The nodules contain more alumina than those of the Upper Greensand (Walker).

The nodules proper of the phosphate beds are of a very variable character, in which respect they resemble the nodules of North and South Carolina. They vary in size from pieces no larger than a grain of sand to masses weighing 3 or 4 pounds. They give off an organic smell when rubbed, have a cubic fracture, and vary from yellow to chocolate brown in color. Their hardness is 3 to 4. The darker nodules are near the bottom of the bed; though, in most cases, the color depends on the substance originally phosphatized (Keeping). The nodules sometimes are of a perfectly homogeneous and opal-like nature. From this they go through all stages of sandiness, till they are simply nodules of phosphatic sandstone. Keeping, in describing them, says:

> There are certain curious branching, interlacing, undulating, or simply straight-crossing structures forming little gutters over the surface of the nodule, and canals penetrating into its substance. * * * Some of these are mere shrinkage cracks and others are the marks of where "episites," such as *Serpulæ* and *Polyzoa*, have been attached to the inner surface of the original shell; others again are probably the work of boring creatures, especially sponges, but the great variety and many peculiarities of type that occur and their constant association with phosphatic nodules are facts not sufficiently explained by the accumulated work of all the above-mentioned agents.[1]

These nodules are not so rich in phosphate of lime as those of the Upper Greensand; they average 40 to 50 per cent. (Völcker), while those above the Gault average 50 to 60 per cent., phosphate of lime (Way). (See analyses.)

[1] This exactly describes the surface of many of the phosphatic nodules of the Alabama Cretaceous formation.

Most of the fossils in these Lower Greensand phosphate beds have been derived from older formations. They are rolled and worn to such an extent that it is frequently impossible to identify them. Keeping, in speaking of the piles of phosphatic material at the mines, says, that "the coprolite heap looks like one mass of *Ammonites biplex*, mostly worn and fragmentary." The fossils are mostly worn species of mollusca of Oxfordian, Kimmeridgean, or Portlandian species of the Upper Jurassic (W. Keeping). Many of the derived species are of the Neocomian age, such as *Ammonites Deshayesii*, *Ancyloceras* sp., *Hamites* sp., *Thetis minor* Sowerby, *Terebratula ovoides* Sowerby, and other forms.

Thus it will be seen that these latter fossils have been derived from a bed but very little older than the nodule bed, as this latter deposit belongs, according to J. F. Walker,[1] to the Upper Neocomian formation. Mr. Walker[2] also thinks that a large number of the derived fossils came from the underlying Kimmeridge Clay. Many of the fossils of the Upware nodule bed are preserved in amorphous or crystalline calcite, others in ferruginous sandstone and phosphate of lime. The fossil wood is silicified. According to W. Keeping, all the shell casts and fossils that have been mineralized by phosphate or limonite are derived fossils and belong mostly to Jurassic species. They are easily recognized by their rolled and water-worn condition. Walker divides the fossils into (*a*) indigenous fauna, preserved in oxide of iron, and (*b*) derived fossils, preserved in phosphate of lime. H. G. Seeley, on the other hand, thinks that all these fossils are natives of the beds in which they are found.

As regards the mode of phosphatization of these beds, Walker, Keeping, Teall, and others agree in the theory that it is the result of the soaking of calcareous substances in decomposed animal and vegetable matter. The Coral Rag fragments in the bed are not at all phosphatized. In this particular the deposit resembles those of Alabama and the Carolinas, where shells perfectly free from phosphatic matter are associated with beds of highly phosphatic nodules and fossils. This would seem to show that the non-phosphatic substances were deposited after the nodules had been phosphatized. But Dr. C. U. Shepard, jr.,[3] and W. Keeping explain the phenomenon by supposing that the purer forms of carbonate of lime are not so susceptible to phosphatization as the impure forms.

A very distinctive feature between the Upper and Lower Greensand phosphate deposits is the nature of the matrix of the nodules in the two formations. As has been already said, the matrix of the Upper Greensand is a calcareous Greensand containing 2 to 10 per cent. of phosphoric acid, while the matrix of the Lower Greensand nodule beds

[1] Mon. Fossil Trigoniæ, Pubs. Palæontographical Soc., vol. 29, 1875, p. 145.

[2] Annals Mag. Nat. Hist., 1866.

[3] South Carolina Phosphates.

is a highly siliceous sand, containing no phosphate, except where the nodules have been decomposed. The siliceous pebbles of these lower beds are of very general distribution. They are found all along the Lower Greensand outcrop in England at Upware, Sutton, Brickhill, Farrington, and other places, also in the Neocomian strata at Schöppenstedt, in Brunswick. Many of these pebbles are fossiliferous.

Mr. Keeping[1] found in some chert pebbles many shells and crinoids of the Carboniferous age. In others he found many Jurassic shells and echinoderms. He thinks most of the pebbles were derived from an ancient barrier axis, which, in the Lower Neocomian period, separated the north from the south Neocomian seas in Europe, but "which was in the time of the deposition of the iron sand series suffering rapid denudation and destruction."

The Lower Greensand phosphate beds have numerous outcrops in Surrey, Sussex, and Kent. They are, however, thought by W. Keeping not to be of the same age as the beds of Cambridge and Bedford, but to belong to the Sandgate and Hythe series.

Tertiary phosphate beds.—The Tertiary phosphate deposits occur in or directly under the various Crag formations of Norfolk, Suffolk, and Essex, but are richest and most extensive in the county of Suffolk. The Crag of Suffolk and Norfolk runs along the coast from about 5 miles northwest of Kromer, in Norfolk, for a distance of 70 to 80 miles to Hardwick, in the northern part of Essex. This belt is from 7 to 22 miles wide, being widest in the neighborhood of Norwich and narrowest at Halesworth, in Suffolk. Beyond these limits the Crag often occurs in patches in the county of Essex. The Suffolk and Norfolk Crag does not extend all over the above mentioned area, but in many places it is covered by alluvium, and in others, especially in Essex and in the south of Suffolk, it has been removed by erosion, and the London clay crops out.

It is in the county of Suffolk, and especially in the district between the rivers Orwell, Deben, and Alde, and in the country surrounding the central mass of Coralline Crag at Sutton, that the Tertiary phosphate beds have been most successfully and profitably worked. The Crag formation of this country is composed largely of the Coralline and Red Crags. These formations are each separable into two divisions. Prof. J. Prestwich[2] has divided the Coralline Crag into the upper part, consisting mostly of remains of Bryozoa, and the lower part, consisting of light-colored sand with many shells mixed in with it. The two beds together are rarely over 20 feet thick, and rest on the London Clay (Eocene). The Red Crag consists of irregularly stratified sands stained with oxide of iron. It comes above the Coralline Crag, though in most

[1] The Fossils and Palæontological Affinities of the Neocomian Deposits of Upware and Brickhill, 1883.

[2] Quart. Jour. Geol. Soc. London, vol. 27, 1871.

cases it rests directly on the London Clay, the Coralline Crag having been eroded. The two divisions of the Red Crag are often very difficult to distinguish. The only difference is that the lower division usually has more shells scattered through it. According to Professor Prestwich, the lower division includes all the beds going under the name of red and Norwich Crag, while the upper division includes the Chillesford sands and clays. Both the Coralline and the Red Crags belong to the Upper Pliocene period and are of the same age as the Upper Antwerp Crag.[1]

The phosphate beds occur at the base of the Coralline and Red Crags and immediately over the London Clay. The bed sometimes thins out, and at other times it separates into two seams, divided only by a few feet of shelly crag. Occasionally, also, nodules, and seams of nodules, are found running through all parts of the Red Crag, though the bed at its base is generally the largest and most continuous. The phosphate bed consists of a mass of phosphatic nodules and shell casts, siliceous pebbles, teeth of cetacea and sharks, and many mammal bones, besides occasional fragments of Lower Greensand chert, granite, and chalk flints. There are numerous fossils and shells, *Cardium edule*, *Pectunculus glycymeris*, *Cyprina islandica*, and other forms. The bed varies from 2 to 18 inches in thickness. The nodules vary considerably in both quality and quantity. They are at times of a compact and brittle nature, while at others they are tough and siliceous. They average about 53 per cent. phosphate of lime and 13 per cent. phosphate of iron. The quantity of bones in the beds also varies very much. Sometimes there are few and at other times there are great quantities of mastodon and rhinoceros teeth and bones of other mammals, similar in some respects to those at Eppelsheim in Germany.[2] Large cetacean bones and teeth of Charcharodon and Oxychina are also found. There is considerable dispute concerning the origin of the fossils and nodules in the phosphate beds of the Crag. That most of them are derived masses is shown by their worn and rounded condition. Mr. Jenyns[3] believes that they have come from the London Clay, and in support of this view he calls attention to the similarity of the nodules of the two formations. Professor Prestwich[4] thinks that most, if not all, of the nodules of the Red Crag came from the Coralline Crag.

The phosphate deposits of Norfolk are few and scattered. Most of the phosphatic material from this county is in the form of mastodon, elephant, and rhinoceros bones from the forest and elephant beds. None of the Crag phosphate beds have proved so valuable as the Cretaceous beds. The nodules are harder and more siliceous, making them more difficult to grind and less valuable as a soil stimulant when in the un-

[1] Geol. Mag., London, 1865.
[2] E. Ray Lankester: ibid.
[3] Ibid., vol. 3, 1866.
[4] Quart. Jour. Geol. Soc. London, vol. 27, 1871.

acidulated state. Besides this, they contain considerable phosphate of iron, which causes a superphosphate, made from such nodules, to have a sticky consistency and to be very liable to "revert" to an insoluble condition.

The Crag nodules resemble those of the Cretaceous formation, as well as some of those of South Carolina, in the fact that the exterior part often contains more phosphoric acid than the interior. The following analyses by T. J. Herapath[1] illustrate this fact:

	Exterior.	Interior.
1	1.105 per cent. fluoride of lime.	0.611 per cent. fluoride of lime.
	40.019 per cent. phosphoric acid.	34.015 per cent. phosphoric acid.
2	3.996 per cent. fluoride of lime.	1.961 per cent. fluoride of lime.
	32.043 per cent. phosphoric acid.	21.046 per cent. phosphoric acid.

History of the rock phosphates of England.—The Greensand of England has been used as a fertilizer for many generations. As early as 1790 it was considered so valuable as a soil stimulant that it was carried in carts, sometimes for many miles, all over the counties of Essex and Kent. Immense pits, dug in the Greensand marl, concerning which there is no historic record and which are now overgrown by large oaks and other forest trees, bear witness to the great value placed on this marl in by-gone times. A remarkable example is seen at Worldham, where there is a large excavation 15 feet deep, from which, once, thousands of tons of greensand were removed. But the heaps of phosphatic nodules which are often found near these pits, and which seem to have been thrown away as worthless, show that the value of this part of the bed was not known.

It was not until nearly the middle of this century that the agricultural value of these nodules was appreciated. Doctors Mantel, Buckland, and Fitton, in the early part of the century, pointed out the existence of beds of nodules and fossils in the Cretaceous and Tertiary formations of England, but simply spoke of them as remarkable beds of fossils and nodules. Mr. Berthier, in 1820, also made analyses of similar nodules found in France. But their use as a plant food was not recognized until Professor Henslow made a study of the Red Crag nodules at Felixtow in 1842, and suggested their use in agriculture before the British Association in 1845. It was at this time that the name coprolite, or fossil dung, was first given to these nodules by Professor Henslow. At a later date he saw his mistake in believing the phosphatic masses to be of coprolitic origin, and considerably modified his views. It was certainly a most unfortunate name, as it has since been shown that real fossil dung is a thing of very rare occurrence, and hence the name coprolite, as applied to beds of nodular phosphates, is misleading.

Among the most active of the early advocates of English phosphates

[1]Jour. Royal Agric. Soc., 1851.

were J. M. Paine and J. T. Way,[1] who analyzed many specimens of the material and made many practical experiments, which went far to open up the phosphate mining industry in England. From that time on the use of the English phosphatic nodules became more and more extensive, until within the last few years the immense exports of phosphate of lime from South Carolina, the West Indies, and other localities have thrown so much of that material on the market that the English deposits have become a source of minor importance.

The principal mining operations are carried on in the counties of Cambridge, Bedford, and Suffolk. According to O. Fisher,[2] writing in 1873, the miners in Cambridge had to pay $700 per acre for the right to dig phosphate and had to return the land to its original level condition and resoil it. With all this expense the average yield was only 300 tons per acre, which sold at $12 a ton; while in the South Carolina diggings the yield is 300 to 1,500 tons per acre and it sold, at that time, for $9 a ton. The nodules in England were dug to the depth of 20 feet, but it did not pay to go any deeper.

Dr. C. U. Shepard, jr., informs me that he visited the diggings at Whaddon, near Rowsley, in 1875. They were then working at the depth of 8 to 18 feet, all the surface beds having been exhausted. Sums from $500 to $1,250 per acre were paid for the right to take the rock, and the yields per acre were from 150 to 400 tons. The mining was done in open trenches. The phosphate rock was washed in circular horizontal tubes and was kept moving by rakes worked by steam. The capacity was about 5 tons daily, and the cost of washing about 85 cents a ton. Wages were $6 a week. The nodules were sun-dried and then carted to the railroad for 50 cents per ton.

The production for the three counties of Bedford, Cambridge, and Suffolk from 1875 to 1881 is given as follows:[3]

	Tons.
1875	250,000
1876	258,000
1877	69,000
1878	54,000
1879	34,000
1880	30,000
1881	31,500

Analyses of the amorphous nodular phosphates of England.

[I. "Molluskite," from the Upper Greensand, by M. Berthier.]

Phosphate of lime	57.00
Carbonate of lime	7.00
Carbonate of Magnesia	2.00
Silicate of iron and alumina	25.00
Water and bituminous matter	7.00
	98.00

[1] Jour. Royal Agric. Soc., 1848.

[2] Quart. Jour. Geol. Soc. London, vol. 29, 1873.

[3] Mineral Statistics of the United Kingdom, by Robert Hunt, F. R. S. (From D. C. Davies, Earthy and Mineral Mining, London, 1884.)

[II. Phosphate from the Upper Greensand, at Dippen Hall (Way).]

Insoluble siliceous matter	9.84
Soluble silica	2.36
Phosphoric acid	27.60
Equal to bone earth phosphate, 59.60.	
Carbonic acid	6.96
Lime	44.56
Magnesia and loss	0.81
Oxide of iron and alumina	4.61
Organic matter	3.26
	100.00

[III. Fossil sponge, a branching Alcyonite from the Upper Greensand (Way).]

Insoluble siliceous matter and soluble silica	7.68
Phosphoric acid	29.87
Equal to bone earth phosphate, 61.30.	
Carbonic acid	8.77
Lime	42.29
Oxide of iron and alumina	6.87
Water, organic matter, fluorine and loss	4.52
	100.00

[IV. Red nodule from the Upper Greensand, at Dippen Hall (Way).]

Insoluble siliceous matter, with a little clay	7.18
Soluble silica	3.28
Organic matter	2.49
Phosphoric acid	27.13
Equal to bone earth phosphate, 55.96.	
Carbonic acid	8.77
Lime	39.85
Magnesia	0.96
Oxide of iron and alumina	10.60
Fluorine	Trace
	100.26

[V. Phosphatic nodules from the Upper Greensand (Völcker).]

Moisture and organic matter	4.68
Lime	43.21
Magnesia	1.12
Oxide of iron	2.46
Alumina	1.36
Phosphoric acid	25.29
Carbonic acid	6.66
Sulphuric acid	0.76
Chloride of sodium	0.09
Potash	0.32
Soda	0.50
Insoluble siliceous matter	8.64
Fluoride and loss	4.96
	100.05

[VI. Upper Greensand from Dippen Hall (Way).]

	Coarse part.	Fine part.
Insoluble siliceous matter	21.85	26.25
Soluble silica	20.18	18.11
Organic matter	6.25	5.95
Phosphoric acid	7.80	10.38
Carbonic acid	10.91	10.34
Lime	20.58	19.87
Magnesia	1.59	0.87
Oxide of iron and alumina	8.18	6.18
Potash and soda, not estimated		
	97.34	97.95

[VII. Upper Greensand from Dippen Hall (Way).]

	Coarse part.	Fine part.
Insoluble siliceous matter	26.83	32.81
Soluble silica	26.30	29.14
Organic matter	2.64	3.02
Phosphoric acid (1)	9.31	6.61
Carbonic acid	2.35	2.30
Lime	15.24	9.53
Magnesia	1.43	1.97
Oxide of iron and alumina	13.11	11.46
Potash	Not est.	3.10
Soda	Not est.	0.00
		99.94
(1) Equal to bone earth phosphate	19.22	
(1) Equivalent of earthy bone		13.63

[VIII. Cambridgeshire glauconite (Professor Liveing).]

Water	10.80
Silica	51.09
Alumina	9.00
Iron (protoxide)	19.54
Magnesia	3.37
Lime	0.30
Soda	3.56
Potash	2.47
	100.13

[IX. Phosphate nodules from Lower Greensand (Way).]

Insoluble siliceous matter	43.87
Soluble silica	3.25
Organic matter, water, and fluorine	3.44
Phosphoric acid	20.80
Equal to bone earth phosphate, 42.48.	
Carbonate of lime	1.06
Lime in combination with phosphoric acid	23.86
Oxide of iron and alumina	3.35
Magnesia and loss	0.37
	100.00

[X. Phosphatic nodule from Lower Greensand (Way).]

Silica and sand	13.64
Sulphate of lime	50.16
Water in combination	14.97
Water (accidental)	7.47
Phosphoric acid	4.80
Lime, additional	0.27
Oxide of iron and alumina	8.82
	100.13

From the above analysis it will be seen that most of the phosphoric acid must have been in combination with iron and alumina.

[XI. Large green grains from a Lower Greensand phosphatic conglomerate (Way).]

Soluble and insoluble siliceous matter	18.53
Water	2.28
Phosphoric acid	20.65
Carbonic acid	4.01
Sulphuric acid	5.13
Lime	34.61
Oxide of iron	7.24
Alumina	0.98
Potash	1.79
Soda	1.87
	97.09

[XII. Lower Greensand nodules (Völcker).]

	Average samples of siftings from layers at 1 and 2 feet.	Washed rock from another place.
Water of combination	5.17	5.67
Phosphoric acid	[1]22.39	[2]15.12
Lime	32.73	26.69
Magnesia, alumina, and fluorine (by difference)	6.64	4.51
Carbonic acid	3.06	[2]2.18
Oxide of iron	[1]8.08	20.61
Siliceous matter	21.93	25.22
	100.00	100.00

[XIII. Partial analysis of phosphatic conglomerate, Lower Greensand, from Folkstone, by Way].

Insoluble siliceous matter	30.60
Phosphoric acid	7.23
Potash	3.31
Soda	1.02

[XIV. Lower Greensand mass, from which the principal fossils and nodules were picked, by Way.]

Insoluble siliceous matter	75.46
Soluble silica	8.12
Organic matter	2.30
Phosphoric acid	0.64

[1] Phosphate of lime, 48.51; carbonate of lime, 6.95.
[2] Phosphate of lime, 32.76; carbonate of lime, 4.95.

Carbonic acid	5.64
Lime	2.01
Magnesia	0.18
Oxide of iron and alumina	5.59
	99.94

Analyses of crag phosphates.

These average 50 to 60 per cent. phosphate of lime (Way).

[I. Phosphate from the crag at Surrey, by Herapath.]

Water	3.400
Organic matter	Trace
Silica with some silicate of alumina and silica of iron	13.240
Chloride of sodium	Trace
Sulphate of soda	Trace
Carbonate of lime	28.400
Carbonate of magnesia	Trace
Sulphate of lime	0.736
Phosphate of lime (tribasic)	21.880
Phosphate of magnesia	Trace
Perphosphate of iron	24.760
Phosphate of alumina	6.998
Phosphate of manganese	Trace
Fluoride of calcium	Some
Loss	0.586
	100.000

[II. Partial analysis of three Suffolk nodules, by Herapath.]

Earthy and other phosphates	64.056	79.545	67.176
Fluoride of calcium	0.311	2.554	2.768
Nitrogen	Traces	0.0314	Undet.

[III. Crag nodules from coast of Suffolk (Herapath).]

Water with a little organic matter	4.000	3.560
Salts soluble in water (chloride of lime and sulphate of soda)	Trace	Trace
Silicic acid, colored red by a little undecomposed silicate of iron	5.792	6.309
Carbonate of lime	10.280	8.959
Sulphate of lime	Distinct trace	0.611
Phosphate of lime (tribasic)	70.920	69.099
Phosphate of magnesia	Trace only	Trace
Perphosphate of iron	6.850	8.616
Phosphate of alumina	1.550	2.026
Oxide of manganese	Trace	0.016
Fluoride of calcium	0.608	0.804
	100.000	100.000
Nitrogen	.0254	Undet.

[IV. Suffolk crag phosphate (Herapath).]

Water driven off at from 300°–350° F	2.600
Water and organic matter, expelled at a red heat	9.000
Chloride of sodium, etc	Evident trace

Carbonate of lime	39.500
Carbonate of magnesia	0.520
Sulphate of lime	Distinct trace
Phosphate of lime	15.860
Phosphate of magnesia	Trace
Perphosphate of iron	9.200
Phosphate of alumina	4.708
Peroxide of iron	None
Alumina	6.212
Fluoride of calcium	1.698
Silicic acid	10.601
	99.899

[V. Suffolk phosphate nodules, by Herapath.]

Water and organic matter	7.200	9.210
Chloride of sodium and sulphate of sodium	Trace	Trace
Carbonate of lime	18.514	5.176
Carbonate of magnesia	0.855	2.016
Sulphate of lime	Some	1.161
Phosphate of lime	51.018	45.815
Phosphate of magnesia	Trace	Trace
Perphosphate of iron	8.902	12.476
Phosphate of alumina	2.700	6.387
Oxide of maganese	0.057	0.267
Peroxide of iron	....	....
Alumina	....	....
Fluoride of calcium	3.161	2.688
Silicic acid and loss	7.593	14.804
	100.000	100.000
Nitrogen	0.0289	0.0198

PHOSPHATES OF BELGIUM.

The phosphate deposits of Belgium belong to the upper part of the Cretaceous formation. They are mined almost exclusively in the province of Hainaut, which is the southern part of the kingdom, and borders on the French province of Aisne. The following section will show the general geologic relations of the phosphate beds of this region:

Tufeau de Ciply (Ciply Marl)[1]	Craie de Maëstricht (in part).
Poudingue de Ciply (Ciply Conglomerate)	
Craie Grise ou Brune (Brown or Gray Chalk)	
Craie Blanche (White Chalk).	

The top bed, Tufeau de Ciply, is a soft, coarse-grained, calcareous rock of a white or light yellow color. It crops out in numerous places in the communes of Cuesmes, Hyon, Ciply, and Mesvin, and rests uncomformably on the underlying beds. In Cuesmes it comes in direct contact with the White Chalk (Craie Blanche), but in Ciply and Mesvin it is separated from it by a considerable thickness of intervening strata,

[1] In his recent memoir (Quart. Jour. Geol. Soc. London, pp. 325–340, 1886) Mr. Cornet expresses the opinion "that the Brown Phosphatic Chalk of Ciply and the Chalk of Spiennes should be regarded as forming together one geological whole, a peculiar stage of the Belgian Cretaceous series."—N. S. S.

as shown in the section above. Immediately under the Tufeau comes the Ciply Conglomerate. This is a denudation deposit, and is known as the Poudingue de Ciply, or Poudingue de la Malogne.[1] In some places it immediately overlies the White Chalk, as in the neighborhood of Ciply, and at others it is separated from it by a very variable thickness of Gray or Brown Chalk. The Conglomerate consists of a mass of phosphatic nodules, shell casts, and fossils, cemented by a calcareous matrix. Sometimes the bed is cemented into a solid mass, and again it is loose, and easily worked with pick and shovel. There are numerous shells and remains of gasteropods, lamellibranchs, brachiopods, sea-urchins, and sponges. There are, also, many teeth and vertebrate bones of fish and sharks, all much worn and rounded, showing clearly that they have been changed from the bed in which they were originally deposited. *Belemnitella mucronata* and *Ostrea vesicularis* are among the common forms found in the bed.[2] The nodules vary from a quarter of an inch to 5 inches in diameter, and are generally of a brown color. They contain a small quantity of phosphate of lime (25 to 50 per cent.) compared with that of American and English phosphates, which rarely run under 55 per cent. and 50 per cent. of phosphate, respectively. When ground and heated in a dark room the Ciply phosphate shows the same phosphorescence as the Spanish phosphorite, but in a less degree. The nodule bed is very continuous at the base of the Tufeau de Ciply,[3] but is generally in such a thin sheet that it does not pay to work it. Occasionally, however, it has been collected in pockets on the surface of the underlying bed, to such an extent that it has been mined with profit. Such is the case in Cuesmes and Ciply, where openings have been made and large quantities of phosphate taken out. The thickness of the bed is very variable, ranging generally from a few inches to 3 feet. The underlying bed is much worn and eroded on the top.[4]

It is from the bed immediately underlying the Ciply Conglomerate that over nine-tenths of the phosphate now mined in Belgium is obtained. This bed is known as the Craie Grise or Craie Brune, and comes between the Ciply nodule bed and the White Chalk (Craie Blanche). It is of a very variable thickness, being in some places entirely eroded, so that the Ciply Conglomerate comes in direct contact with the White Chalk. At other localities it reaches a very considerable thickness, as near the town of Ciply, where it is 30 meters deep. The bed consists of a coarse-grained rock, easily crumbled in the fingers, softer at the top than at the bottom, and of a gray or brown color. It is formed of a mixture of grains of carbonate of lime and small pebbles of phosphate of lime, about the size of a pin head. The proportions of the two constituents

[1] Cornet and Briart: Bull. Acad. roy. Belgique, 2d series, vol. 37, 1844, pp. 338, 844.
[2] F. L. Cornet: Bull. Soc. géologique France, 3d series, vol. 2, 1874, p. 570.
[3] Mr. Melsens: Bull. Acad. roy. Belgique, 2d series, vol. 38, 1874, pp. 25–52.
[4] F. L. Cornet: Bull. Soc. géologique France, 3d series, vol. 2, 1874, pp. 567–577.

are about 25 to 30 per cent. of grains of carbonate of lime, and 70 to 75 per cent. of phosphatic pebbles. The phosphate grains are equally plentiful all through the upper 10 feet of the bed, but below this they begin to grow scarcer and scarcer, until the bed gradually runs into the White Chalk (Craie Blanche). In this lower bed no phosphatic nodules are found, but in their place there occur beds of brown, siliceous nodules lying between the strata. The overlying phosphate bed (Craie Grise or Craie Brune) is a regularly stratified deposit and dips gently to the northwest.

The phosphate grains were at first thought to be glauconite which had been turned brown by weathering. They are of a brown color and are very porous. When exposed to the action of heat for some time they become crumbly and very easy to grind. This is explained by Mr. Nivoit[1] as being caused by the decomposition of the animal matter in the nodules. The specific gravity is 1.80 to 2.90. The phosphatic bed runs in a band of several hundred meters' breadth, through Cuesmes, Hyon, Ciply, Mesvin, Nouvelles, and Spiennes, all in the province of Hainaut. Estimating the surface of the belt as 180 hectares (444.78 acres), and supposing that mining can be carried on to a depth of 8 meters, there would be 14,500,000 cubic meters of workable rock in the place.[2]

The upper part of the phosphate bed averages 11.50 per cent. of phosphoric acid (see analyses p. 107). A large part (50 to 55 per cent.) is composed of carbonate of lime. Numerous methods have been tried to separate the phosphate from the matrix. Treating the mass with hydrochloric acid[3] has been tried, in the hope of dissolving out the carbonate and leaving the phosphate untouched, but it was found that the acid attacked the phosphate at the same time as it did the carbonate. Another method is to expose the mass of nodules and matrix to the air for some time in order to allow it to disintegrate. It is then separated from a part of the associated carbonate of lime by shaking on a screen, or washing in a stream of running water, which carries off the more finely divided part of the carbonate. Sometimes the rock is ground, and a considerable part of the limestone removed by a fan. This method is, however, not as efficient as the washing process, and is only used where water is scarce. By none of these processes has the quality risen above 40 to 50 per cent. phosphate of lime.[4]

An examination of the analyses given will show that the freer the phosphatic grains are from the calcareous matrix, the nearer they approach in composition to the nodules of the Ciply Conglomerate.[5] They

[1] Mr. Nivoit: Comptes rendus Acad. sci., Paris, vol. 79, 1874.

[2] Cornet and Briart: Bull. Acad. roy. Belgique, 2d series, vol. 37, 1874, p. 841.

[3] A. Petermann: Bull. Acad. Sci. Roy. Belgique, vol. 39, 1875, p. 31.

[4] According to Cornet experiments are now in progress which indicate that the proportion of phosphate may be raised to 65 per cent. See Quart. Jour. Geol. Soc. London, vol. 42, 1886, p. 334.—N. S. S.

[5] Mr. Nivoit: Compt. Rendus Acad. sci., vol. 79, Paris, 1874.

resemble very much in composition the nodules of the Marnes Crayeuses in France. The Poudingue de Ciply and the underlying Craie Grise or Craie Brune combine to make a formation very similar to the phosphate conglomerate of New Hanover County, the Poudingue resembling the upper part of the New Hanover bed and the Craie Grise or Craie Brune resembling the lower part. As will be seen by referring to the description of the North Carolina bed, the upper part contains much larger nodules and is more compact than the lower part, which is of a loose texture and has nodules of more uniform composition than the upper part. The nodules of the lower part of the New Hanover bed resemble those of the Craie Grise or Craie Brune both in decreasing in quantity at a depth and in their brown color. The principal differences are that the American beds are of Tertiary age, while the Belgium beds belong to the Cretaceous period. The nodules are smaller in the Chalk beds than in the lower part of the New Hanover beds, while the nodules of the Ciply Conglomerate are apt to be larger than those of the upper New Hanover bed. Also, the nodules of the upper part of the New Hanover beds are of more variable physical and chemical character than those of the Ciply Conglomerate.

The phosphates of the Ciply Conglomerate bed were discovered as early as 1858 by Mr. Lehardy de Beaulieu,[1] and were described again in 1866 by Messrs. Cornet and Briart.[2] But it was not until 1873 when Messrs. De Cuyper and Gendebien and Mr. Desailby opened mines, that the phosphates of Belgium were worked.

The phosphates of the Craie Grise were discovered in 1873 by Messrs. Cornet and Briart,[3] and since that time they have been almost the only beds worked, as they have proved more profitable than the Conglomerate bed. The mining is generally done in open trenches, though shallow shafts are sometimes sunk, and horizontal galleries are run in from the sides for a distance of 10 to 12 meters.

[1] Mémoires et Pub. Soc. sci. Hainaut, 2d series, vol. 7, 1860.

[2] Bull. Acad. Roy. Belgique, vol. 22, 1866.

[3] Bull. Acad. Roy. Belgique, vol. 37, 1874.

NOTE.—As this report is going to press I have received a memoir of Mr. F. L. Cornet, published in the Quarterly Journal of the Geological Society of London, August 2, 1886, pp. 325–340, entitled "On the Upper Cretaceous series and the Phosphatic beds in the neighborhood of Mons (Belgium)." This valuable memoir contains some important information concerning the geological and economic history of the region about Mons. The most important points are summarized below:

Production of the Mons district in English tons.

Year.	Tons.	Year.	Tons.
1877	3,850	1881	29,528
1878	5,630	1882	40,043
1879	7,578	1883	58,660
1880	15,500	1884	85,000

The most important points set forth in this contribution concern the circumstances which have led to the formation of the phosphates of the Mons district. The author

Analyses of the amorphous nodular phosphates of Belgium.

[I. Ciply Conglomerate nodules (A. Petermann, Bull. Acad. roy. Belgique, vol. 39).]

Water and organic matter	6.39
Carbonate lime	40.55
Phosphate lime (21.82 phosphoric acid)	47.63
Sulphate lime	3.19
Silica	0.31
Magnesia (chlorine and alkalies not determined)	1.93
	100.00

[II. Nodules (Nivoit, Assoc. franç. avanc. sci., 1875).]

Constituents.	From Perthes, at base of Craie Blanche.	From Ciply Conglomerate.	Craie Grise (whole mass, nodules and matrix).
Loss by calcination (1)	25.10	25.55	31.00
Sand and clay	1.65	1.30	2.10
Oxide of iron	1.20	0.90	1.10
Lime	50.89	51.60	54.00
Phosphoric acid (2)	21.10	20.35	11.13
Sulphuric acid	....	0.12	....
Chlorine	0.14	0.25	....
Fluorine	....	0.18	....
	100.08	100.25	90.33
(1) Equal to phosphate of lime	46.06	44.42	24.30
(2) Nitrogen *a*	0.25	0.35	....

a Some of the nitrogen is in the form of ammonia salts.

clearly shows that these phosphates have been formed by the concentration of phosphatic matter originally disseminated in lime carbonate, the concentration having been effected by the action of water containing carbonic acid gas derived from decayed vegetation. Even in its somewhat concentrated form the proportion of lime phosphate is too low and that of lime carbonate too high for the material to be used in the manufacture of superphosphates. "But," says the author, "by simple mechanical processes, either by dry or wet methods, a product is obtained which contains from 40 to 50 per cent. of phosphate. Some experiments now being made lead us to hope that a proportion of 65 per cent. may be reached." These experiments in concentration have a great interest to us, for the reason that they may show the way by which the low-grade phosphates of Alabama and other parts of this country can be utilized.

The diagrams accompanying this report are of interest, as they show the relation of the phosphatic deposits to the erosive agents which have served to bring about this concentration in superficial beds.—N. S. S.

[III. Craie Brune (Nivoit, ibid.)]

Constituents.	Nodules and matrix mixed.	Washed nodules.
Organic matter	2.83	4.40
Lime	53.24	52.00
Magnesia	0.12	Trace
Alumina and oxide of iron	1.01	1.29
Potash and soda	0.19	0.28
Carbonic acid	28.10	24.32
Sulphuric acid	0.89	0.92
Phosphoric acid	11.66	15.19
Silica and sand	1.96	1.60
Chlorine and fluorine	Trace	Trace
	100.00	100.00

[IV. Craie Brune (Petermann, Bull. Acad. Sci. roy. Belgique, vol. 39, p. 34).]

	Phosphoric acid.
(*a*) Mass poor in phosphate grains	10.60
(*b*) Mass poor in phosphate grains	9.27
(*c*) Mass rich in phosphate grains	13.90
(*d*) Incoherent fragments	10.87
(*e*) Incoherent fragments	11.62
(*f*) Incoherent fragments	10.87

[V. Craie grise ou brune (Nivoit, Assoc. française avanc. sci., 1875).]

Loss by calcination	31.00
Sand and clay	2.10
Phosphoric acid	11.13
Lime	54.00
Oxide of iron	1.10
Loss and undetermined matter	0.67
	100.00

PHOSPHATES OF NORTHERN FRANCE.

The phosphates of northern France occur mostly in the provinces of Ardennes and Meuse, though they are also found in smaller quantities in other northern provinces. They are in the Cretaceous, and, like the phosphates of the English Cretaceous, appear both at the summit and base of the Gault (Gault Argileux). But there is also a third bed, which is not found in England, and which occurs immediately under the Craie Blanche, a calcareous bed corresponding to the Upper Chalk of England. The following section will show the relative positions of these beds, in descending order:

(1) Craie Blanche ("Upper Chalk").
(2) Marnes Crayeuses ("Chalk Marl").

(3) Sables Glauconieux (Chloritic Marl of England).
(4) Gaize (Upper Greensand of England).
(5) Gault Argileux (Gault of England).
(6) Sable Vert (Lower Greensand).

The above section can be seen in many places in the western part of the provinces of Ardennes and Meuse.

The nodule beds in the Upper and Lower Greensand resemble, in many respects, the corresponding beds in England. The Lower Greensand has a very variable thickness, sometimes running out almost entirely, and at others attaining a depth of 50 feet. It is at the base of this mass of sandy clay, colored sometimes by grains of glauconite, that the Lower Greensand phosphate bed occurs.[1] The nodules are rounded, worn, and mixed with many fossils and shell casts. They vary from the size of a nut to that of a man's fist. They are of a brown color, and are generally of a lighter hue on the surface than in the center. Sometimes the nodules occur loose in the sand and at others, as at Clermont and Varennes, they are cemented into a conglomerate. There are in the bed numerous shark teeth, shells, remains of crustaceans, and other fossils. The nodules often contain grains of quartz and greensand, veins or crystals of pyrite, gypsum, and sometimes of galena. There are also often associated with them concretions of pyrite, crystals of gypsum, and balls of ferruginous clay.

The French nodules resemble the English in being of a variable consistency, sometimes being very compact and glassy in appearance, and at others being so siliceous that they often, as at Beurey, look like grains of sand cemented by a little phosphate. It has already been shown that the composition of such nodules, at least so far as the relative amounts of silica and carbonate of lime are concerned, depends largely on the character of the water bottom from which the nodules were formed.

The nodule bed of the French Lower Greensand is very continuous and rarely runs out,[1] though it varies considerably in thickness, ranging from two to nine inches, and averaging about seven inches.[2] There are also nodules, more or less phosphatic, scattered through the overlying Lower Greensand, as well as through the Gault, but they are not in sufficient quantities to be of any commercial importance. The nodules and shell casts of the Gault are much more homogeneous and compact in their composition than those of the Lower Greensand.[3]

The next phosphate bed, in an ascending series, comes in the Upper

[1] Mr. Nivoit: Assoc. franç. avanc. sci., 1875.

[2] The nodules contain 8.80 to 50.54 per cent. phosphate of lime and average 39 per cent.

[3] It will be seen that there is only one regular bed of nodules in the French Lower Greensand, while in the English formation of the same horizon there are three beds, which, however, often run into each other and form one stratum.

Greensand, or "Gaize," which is a lenticular deposit lying between the Gault beneath and the Sables Glauconieux above. It reaches its maximum thickness of 105 meters near the town of d'Antry. It runs out in the north at d'Attigny and in the south near Nettancourt. It is a more or less clayey and siliceous deposit, often containing a large amount of silica in a semi-gelatinous form. The phosphate bed lies about 50 feet from the base of this deposit, and is irregular and undulating. It is of variable thickness, ranging from two to twelve inches and averaging about five inches.[1] The nodules average 55 per cent. phosphate of lime and are of the same general character all through the bed. Their surface is black or dark green, and is richer in phosphate than the interior, which is often simply a mass resembling in every respect the Gaize formation surrounding the nodules. In this respect these resemble some of the English phosphates, which are often found to contain 50 per cent. of phosphate on the exterior part, while towards the interior the quantity of phosphoric acid grows less and less till, in the center of the nodule, there is a mass of marly sand or sandy marl. The fossils are very numerous and are all much rolled and worn. In the Sables Glauconieux, which overlie this bed, there are found very similar nodules. They do not, however, occur in a regular stratum, but are scattered through the formation.

The last bed of phosphate, in an ascending series, which is found in the Ardennes and Meuse Cretaceous, lies at the base of the Craie Blanche (Upper Chalk), and on top of the Marnes Crayeuses (Chalk Marl). These nodules differ considerably from the underlying phosphates. They are of a white or gray color, homogeneous in composition, and consist almost entirely of carbonate and phosphate of lime. The bed is of very little commercial importance, as it is thin, irregular, and apt to run out.

All these French Cretaceous phosphates are very soft and porous, and can absorb a large amount of water. They easily disintegrate on exposure to air, and are readily ground to an impalpable powder. In fact, those of the Marnes Crayeuses are so soft that they go to pieces while being washed, and are, therefore, not much used. The French differ from the Belgium nodules in having more siliceous matter and less carbonate of lime.[2]

The nodules are dug in trenches or in shafts, from which galleries thirty to forty feet long are run. They are washed by throwing them on a screen over which a stream of water is running, thus reducing the mass to from one-half to one-third of its original weight. When water is scarce they are allowed to lie exposed to the air until dry, and then shaken on a screen. Thus cleaned they retain 10 to 15 per cent. of their original matrix. They are then broken and ground.

[1] Nivoit: Assoc. franç. avanc. sci., 1875.

[2] Mr. Nivoit thinks that the nodules were formed by a phosphatic solution coming in contact with carbonate of lime either already deposited or being deposited.

The principal phosphate mining districts are the canton Grand Pré, in Ardennes, and the cantons Clermont, Louppy-le-Château, and Villotte, in Meuse. The nodules of the Lower Greensand have been more extensively mined than the other beds, having been worked in seventy communes; while the Upper Greensand nodules are worked in twelve, and the Marnes Crayeuses in only one commune (at Sainte Marie, near Vauziers). The nodules at the base of the Craie Blanche have not been profitably worked in either Ardennes or Meuse.

The production of phosphate of lime from the north of France in 1875 was 66,000 tons, of which 41,000 came from Meuse and 25,000 from Ardennes, and 1,500 workmen were employed in washing and mining.

Following is a table[1] showing the cost of mining and shipping one cubic meter of nodules from the Lower Greensand, allowing 1,500 kilograms to the cubic meter. Also a table showing the expense of treating in the same way one cubic meter of Upper Greensand nodules, allowing in this case a weight of 1,600 kilograms to the cubic meter.

Cost of mining and shipping phosphates of northern France.

Items of expense.	Lower Greensand.	Upper Greensand.
	Francs.	*Francs.*
Cost for right to dig	4.00	10.00
Extraction	15.75	31.00
Transportation to washers and from them to mill	4.00	4.00
Washing	2.50	5.00
Grinding and putting in bags	9.00	10.40
Shipping (expédition)	1.75	2.50
Extra costs (traisgénéraux)	5.00	5.00
Total for a cubic meter	42.00	67.90
Total for a ton	28.00	42.45

Analyses of amorphous nodular rock phosphates of northern France.

[I. Grand Pré nodules, Upper Greensand, by Nivoit.]

Loss by calcination	8
Clay, sand, and greensand	42
Phosphoric acid	20
Lime	27
Oxide of iron	3

[II. Nodules from base of Craie Blanche by Nivoit.]

Loss by calcination	25.10
Clay and sand	1.65
Phosphoric acid	21.10
Chlorine	0.14
Lime	50.89
Oxide of iron	1.20
	100.08

[1] Nivoit: Assoc. franç. avanc. sci., 1875.

[III. Similar nodules, analyzed at the École des Mines, Paris.]

Silica	4.80
Alumina and oxide of iron	3.20
Carbonate of lime	45.82
Phosphate of lime	46.13
	100.00

[IV. Sables Verts nodules, by Nivoit (Assoc. franç. avanc. sci., 1875).]

	I. From Islettes.	II. From Louppy le Château.	III. From d'Andernay.	IV. From Beurey.
Loss by calcination	15.00	9.60	10.50	8.00
Sand and clay	27.98	23.80	31.03	39.80
Phosphoric acid	18.72	22.03	18.78	16.30
Sulphuric acid	....	2.12	0.89	0.92
Oxide of iron	4.30	11.30	15.65	10.60
Lime	21.00	29.33	20.80	22.00
Magnesia	2.10	Trace.	Trace.	0.89
Loss and matter not determined	0.90	1.82	2.35	1.49
Total	100.00	100.00	100.00	100.00

[V. Gaize nodules from Grand Pré, by Nivoit.]

Loss by calcination	7.20
Sand and clay	13.50
Phosphoric acid	31.00
Sulphuric acid	1.00
Oxide of iron	7.50
Lime	38.50
Loss and matter not determined	1.30
Total	100.00

[VI. Nodules from the Marnes Crayeuses, Sainte-Marie, by Nivoit.]

Loss by calcination	16.20
Sand and clay	26.30
Phosphoric acid	18.00
Oxide of iron	12.15
Lime	27.35
Total	100.00

PHOSPHATES OF CENTRAL FRANCE.

The phosphates of the center of France, in the department of Côte-d'Or, and in the southeast, near the source of the Rhone, around Bellegarde, are of the Lower Gault and Lower Greensand formations. They differ in no material way from the corresponding beds in Ardennes and Meuse. The same formations are worked farther south along the Rhone, at Seyssel, near Grenoble, and elsewhere. In Isère and Drome there is a bed not represented in the north; it is a thin, glauconitic stratum, lying between the Valenginien and the Marnes d'Hauterive. It contains *Belemnites dilatatus* and *Belemnites pestilliformis*. The same bed also crops out near Castellane and Nice. It is of very little commercial importance.

The phosphate bed of Côte-d'Or consists of a bed of yellow sand of fine texture, mixed with shells, fossils, and phosphatic nodules, which often form a separate bed in the sand. The bed immediately underlies the gray and red clays of the Gault.

PHOSPHATES OF RUSSIA.

The principal phosphate deposits in Russia are found in the Cretaceous formation, though deposits of very limited extent have also been found in the Tertiary, Jurassic, and Silurian. The Cretaceous phosphates are developed here on a larger and more continuous scale than those of any other part of Europe or those of America. The main deposit lies between the Volga and the Dnieper Rivers, and the area covered has been estimated by Yermoloff at 20,000,000 hectares (about 50,000,000 acres). It begins in the government of Smolensk and extends almost uninterruptedly in a southeasterly direction to beyond Woronesch. This area is about 370 miles long by 60 to 125 wide. South of this belt the phosphate bed is lost under the overlying beds, but it reappears again on the southern boundary of the Cretaceous basin. North of Woronesch the bed has been destroyed by erosion, but it is found again 125 miles northwest, in the neighborhood of the villages of Tambof and Spask and Simbirsk. Besides these principal localities, the phosphate bed is found in several other places between the Baltic, Caspian, and Black Seas. Mr. Yermoloff,[1] in speaking of the great extent of the Russian phosphates, says:

> Nous ne croyons pas exagérer en affirmant que la Russie centrale repose sur du phosphate de chaux, qu'elle pourrait en paver la moitié de l'Europe, tant les couches qu'elle renferme sont inépuisables de richesses.

The Cretaceous series in central European Russia forms a basin, only the northern boundary of which has as yet been thoroughly explored. The phosphate beds are found at two different horizons in this formation. The first is at the base of the White Chalk or Craie Blanche, and corresponds to the White Chalk bed of Ardennes and Meuse. The second is at the base of the Greensand (Cenomanian, or Grès Verts) and is mixed with glauconite and sand. It corresponds to the beds of the same horizon in central and northern France. The deposit at the base of the Chalk is the most important, and the one most often seen. The phosphatic material occurs in the form of shell-casts, nodules, and fossils, mixed together in a bed of gray or yellow sand, and is commonly known as "ssamorod" (native stone). The nodules are of a black-brown or gray color, and are often cemented together, forming a solid mass, which is used as a building and paving stone. The phosphate often occurs in several different beds, separated only by a thin layer of calcareous or

[1] Alex. Yermoloff: Jour. agric. pratique, 1872.

MAP
OF
EUROPEAN RUSSIA
SHOWING THE PHOSPHATE BEDS

PHOSPHATE BEDS
PROBABLE EXTENSION OF BEDS

siliceous matter. There are usually from one to three of these separate beds and sometimes as many as seven. Their thickness varies from 6 to 20 inches.

The following sections by Dr. C. U. Shepard, jr., will show the position of the phosphate beds:

Section 1. In the township of Briansk, government of Orel, on the banks of the Desna, the ssamorod occurs in large flat pieces, 3 to 4 feet square and 10 inches thick.

The order of occurrence is as follows:

(1) Argillaceous marl.

(2) White chalk.

(3) Siliceous marl, with thin layers of chalk and small nodules of phosphate of lime 1½ feet thick.

(4) Ssamorod occurring (as above described) in flat slabs.

(5) White sand 2 feet thick.

(6) Second deposit of ssamorod, in nodules; 8 inches thick.

(7) Brown sand over 5 feet thick.

The upper deposit of phosphate slabs consists of hard brown nodules, cemented together by siliceous and calcareous matter. The lower layers are dark green and soft when first dug.

Section 2. The same slabs also occur in the neighborhood of Kursk and towards Orel. At Dmitrovsk the occurrence is as follows:

(1) Red clay, 7 feet thick.

(2) White, calcareous marl, containing many small, phosphatic nodules, 4 feet thick.

(3) Very small nodules of phosphate cemented by calcareous matter, 14 inches thick.

(4) Thin layer of brown quartz sand with small nodules.

(5) Phosphatic slabs, 10 inches thick.

These slabs are not flat on the upper side, but irregular and kidney-formed. The size of the slabs varies considerably; some are as large as 3 feet long by 2 wide.

Section 3. The occurrence at Jablovsk is as follows:

(1) Soil and earth.

(2) Marl, a few feet in thickness.

(3) Chalk, a few feet in thickness.

(4) Siliceous marl, with fine grains and pebbles of phosphate, 1 to 2 feet thick.

(5) Sand a few inches thick.

(6) Phosphate rock.

Here the rock comes to sight on the sides of water-worn gullies in the rolling country.[1]

The phosphate stratum underlies an immense extent of country, but it is often at such an inaccessible depth, that most of it is of but little practical value, and it can only be profitably mined where it crops out in the ravines. Besides their inaccessibility, the nodules are of poor quality, varying, as they do, in their content of phosphoric acid from 12 to 35 per cent., and averaging only 20 per cent.[2] The nodules are very siliceous, the grains of sand being plainly visible in them. In this respect they very much resemble the North Carolina Tertiary phosphates.

---

[1] Dr. C. U. Shepard, jr., MSS.

[2] Alex. Yermoloff, Jour. agric. pratique vol. 1, 1872.

When the nodules are cemented together in slabs, the masses are generally 1 to 2 feet square and 8 to 12 inches thick. Their upper surface is smooth, shiny, and mammillated; the lower one, which is irregular and uneven, shows plainly that the slabs are composed of nodules held together by a siliceous and calcareous cement.

According to Yermoloff the beds of Smolensk, Orel, Kursk, and Woronesch contain not less than 6,000 tons per acre, while those of Tambov, which are said to be the richest in Russia, contain 20,000 to 30,000 tons per acre.

As regards the origin of these phosphates, Count Keyserling thinks that they were formed by carbonated waters dissolving the phosphate of lime of the bones and other phosphatic matter of dead animals and redepositing it in a bed of siliceous and calcareous marl.

The existence of ssamorod in central Russia has been known ever since the early part of this century, but its value was not appreciated. In the geological survey of Russia, by Sir R. Murchison, the phosphate rock is simply spoken of as "a shelly agglomerate and concretionary iron-stone," and several deposits of it are spoken of as "ferruginous, siliceous, and concretionary banks." The discovery that ssamorod is a phosphatic rock is due to Professor Chodneff, of St. Petersburg, in 1845. Count A. Keyserling and Professor Claus, of Dorpat, first made known the existence of phosphate in the departments of Kursk and Woronesch a few years later. In 1866, Professor Engelhardt, in his geological survey of Russia, afforded valuable information concerning the extent, value, and accessibility of the phosphatic beds.

Several factories have been started to make use of these deposits, but generally with little success. Large works were started at Ukolowa, Riga, and in Kursk, but were soon closed. The phosphate is of too low grade to pay for the expense of mining it.

Besides the beds already described, phosphatic deposits of much more limited extent have been found elsewhere in Russia. Thus Professor Schwackhofer,[1] of Vienna, has discovered a deposit of phosphatic nodules in the Silurian schists of Poland, on the Dniester. The average of twenty-five analyses gave 74.23 per cent. bone phosphate, which is much higher than the average of Russian Cretaceous phosphates. The amount of phosphatic material in the bed is, however, very limited, and consequently it is of no commercial importance. A phosphatic limestone containing 12 per cent. of phosphoric acid had also been discovered in the government of Novgorod.[2]

[1] Ueber das Vorkommen und die Bildung von Phosphoriten an den Ufern des Dniesters in Russisch-Podolien, Galizien und der Bukowina, by Professor Schwackhofer.

[2] A. Yermoloff, Jour. agric. pratique, vol. 1, 1872.

Analyses of the amorphous nodular phosphates of Russia.

[Analyses given Dr. C. U. Shepard, jr., by T. Lahusen, of the Imperial School of Mines, St. Petersburg.]

[With the exception mentioned under the head of notes all the samples analyzed were nodular.]

Locality.	Government.	Chemist.	Bone phosphate of lime.	Sand.	Notes.
Belskaga in Roslavl.	Smolensk.	Engelhardt...	31.15	43.69 to 50.13	Siliceous.
Do........	....do.....	Kostytscheff..	60.42 to 63.39	5.51 to 7.61	Argillaceous.
Seschti in Roslavl.	....do.....	Schmidt......	36.18	44.57	Siliceous.
Briansk........	Orel......	Engelhardt...	35.25 39.26	39.77 37.43	Green and soft. Brown and hard.
Do........	....do.....	Latschinoff...	33.37	48.25	Prepared phosphate meal.
Voronova......	....do.....	Malyschaff...	45.36	28.79	
Linbachina in Briansk.	....do.....	Morkjraff.....	31.92	47.47	Gray.
Do........	....do.....	Latschinoff...	62.65	9.15	Black.
Kotovetz in Schtyrovosk.	Kursk....	Malyschaff...	59.01	11.97	Cemented in siliceous chalk.
Kursk........	....do.....	Latschinoff...	28.92 to 30.89	57.10 to 53.70	Upper side of flat cakes. Lower side.
Turoff........	Woronesch	Malyschaff...	36.87	44.92	
Jendovischti...	....do.....	....do........	29.92 to 40.47	43.29 to 50.45	
Bondary.......	Tambov..	Yermoloff.....	36.18 to 41.24	45.26 to 35.50	
Bytschkoff.....	....do.....	....do........	15.98 to 60.76	13.03 to 54.16	
Spask.........	....do.....	....do........	60.00	9.50	
Do........	....do.....	....do........	40.32	41.28	
Do........	....do.....	....do........	58.64	12.25	Argillaceous.
Do........	....do.....	....do........	27.57	59.70	Do.

[Analysis by Dr. C. U. Shepard, jr., of phosphate rock ground at the mill at Ukolowa, Central Russia.[1]]

Quartz	34.05
Organic matter	0.90
Sulphate of lime	1.60
Bone phosphate of lime	42.05
Carbonate of lime	12.23
Fluoride of lime	6.98
Phosphate of magnesia	1.30
Alumina and oxide of iron	1.16
	100.27

[By Dr. C. U. Shepard, jr., Jablovsky phosphate rock.[2]]

Phosphoric acid	13.35
Equivalent bone phosphate of lime	29.14
Sand and insoluble siliceous matter	54.40

[1] Ground phosphate rock partially freed from sand.

[2] A superphosphate made from 12 parts (by weight) of this phosphate and 9 parts of sulphuric acid (specific gravity 1.50) gave a product which was wet, sticky, and acid.

[Analysis of Russian phosphate rock, by Yermoloff.]

Phosphoric acid	20.26
Lime	29.07
Magnesia	0.00

[Russian rock phosphates, by Yermoloff.]

	Clay and sand.	Phosphoric acid.	Carbonic acid.	Sulphuric acid.	Lime.	Magnesia.	Alumina and oxide of iron.
Block phosphate from near Kursk, by Claus	50.00	13.60	3.45	.86	21.00	0.65	2.20
Nodules from near Spask, by Yermoloff	9.50	27.48	3.95	1.06	42.00	0.40	3.19
Nodules from near Spask, by Yermoloff	59.70	12.63	1.98	0.44	18.54	......	......
Block of nodules from one of the richest beds of the government of Tambov, by Yermoloff	35.50	20.26	......	0.85	29.07	......	3.47
Fossil bone from same locality as last, analyzed at Agricultural Institute of St. Petersburg	1.45	31.76	......	......	48.53	1.48	0.32
Fossil wood from phosphate bed near Spask, by Engelhardt	......	35.23	3.44	......	51.90	......	1.15
Phosphate from government of Orel, analyzed at the Agricultural Institute of St. Petersburg	7.10	29.84	6.06	1.39	47.99	0.47	0.89

[Analysis of Silurian phosphate rock from the Dniester, by Professor Schwackhofer.]

Phosphate of lime	74.23
Sand and insoluble matter	5.61
Fluoride of lime	6.00
Oxide of iron	0.50–5.0

PHOSPHATIC LIMESTONE BEDS.

Under this heading are included those sedimentary limestones which contain considerable quantities of phosphate of lime. Such deposits have been found in Kentucky; and Yermoloff mentions that a limestone containing 12 per cent. phosphate of lime exists in the government of Novgorod, Russia.

Most limestones contain a small per cent. of phosphate, but as yet very few have been found which contain large amounts, and none are known which have become of commercial importance.

PHOSPHATIC LIMESTONES OF KENTUCKY.

Several beds of phosphatic limestone have been discovered by Prof. N. S. Shaler in Kentucky, but the one richest in phosphate of lime was found in Fayette County.[1] It belongs to the lower part of the Cincinnati group and consists of a thin stratum, never reaching a greater thickness than from 6 to 12 inches. It is a "somewhat friable rock of a bluish gray color; brownish gray on the weathered surfaces; containing many microscopic marine univalve shells. Adheres strongly to the tongue." It is much more brittle than the associated limestones, and contains 31.815 per cent. of phosphoric acid. It is probable that beds of

[1] Geol. Survey Kentucky, N. S. Shaler, Director, 1878, New Series, vol. 4, p. 65.

this kind derived their phosphate of lime from the numerous animals, having phosphatic shells, which inhabited the Silurian sea.

Phosphatic limestone beds, like those just described, supply the soil of the surrounding country with large quantities of phosphate of lime, and it is very likely that the wonderful fertility of some districts in the limestone regions of Kentucky and Virginia is due to the decomposition of such beds.

Analysis of Fayette County phosphatic limestone, by Dr. Peter (Kentucky Geol. Surv., 1878). Dried at 212° F.

Phosphoric acid, lime, magnesia, alumina, iron oxide	85.270
Carbonate of lime	9.180
Carbonate of magnesia	.371
Silica and insoluble silicates	4.780
Fluoride of calcium, alkalies, organic matter, etc., not estimated	.399
Total	100.000

GUANOS.

The class of guanos includes all those deposits which are largely, or entirely, composed of the excrement of birds. Such deposits are subdivided into *soluble guano* and *leached guano*. The former is composed of deposits which have preserved all, or a large part of, their soluble ingredients, while the latter includes such as have lost these soluble constituents by the action of rain or sea-water, and have been converted into a mass, insoluble, or almost insoluble, in water, and varying, in consistency, from a loose powder to a hard compact rock.

The soluble guanos will be treated first, and then the leached guanos will be described.

SOLUBLE GUANO.

Most of the soluble guano of commerce has come from the coast of Peru. It has been used in that country for agricultural purposes from very ancient times. Of such value was it esteemed by the natives that the punishment of death was imposed by the early Incas and their Spanish successors on any one who was found killing the birds that made these precious deposits. Peruvian guano was first recommended (1804) to be used in the raw state for agricultural purposes in Europe by Humboldt, who brought a specimen from the islands off the coast of Peru; but it was not exported in any considerable quantities until 1842, when 182 tons were shipped to England. After that time the use of it increased very rapidly until 1870–1875, when the best beds were exhausted, and the use of acidulated phosphates gradually drove the poorer qualities almost entirely out of the market. It is still imported to the United States and Europe as a source of superphosphate. In the raw state very little of it is used compared with the immense quantities of superphosphates now sold.

The following tables will show the imports into Great Britain, Germany, and France:

Imports into Great Britain (Stockhardt).

	Cwt.		Cwt.
1844	208,502	1855	6,101,220
1845	568,600	1856	3,830,020
1846	1,784,060	1857	5,767,240
1847	1,647,840	1858	7,070,820
1848	1,428,280	1859	1,682,440
1849	1,668,760	1860	2,828,700
1850	2,338,500	1861	3,568,460
1851	4,860,280	1862	2,832,720
1852	2,597,780	1863	4,671,480
1853	2,463,320	1872	117,089
1854	4,470,222	1873	184,921

Imports into Germany (Meyn).[1]

	Tons.		Tons.
1861	25,000	1866	55,621
1862	30,000	1867	52,413
1863	48,785	1868	73,922
1864	50,699	1869	85,233
1865	59,940		

Imports into France (Meyn).[1]

	Tons.		Tons.
1857	52,000	1862	46,000
1858	38,000	1863	68,000
1859	33,000	1864	69,000
1860	40,000	1865	47,000
1861	38,000	1866	57,000

The deposits of guano are found mostly on the islands on the coast of Peru and Bolivia. They are also found on the mainland, but these are not so large as those on the islands. The deposits consist of the excrements of flamingoes, divers, penguins, and other sea fowls, mixed with the carcasses of these birds, as well as those of seals, sea-lions, and other marine animals, which inhabit these seas in vast numbers. The guano is generally pulverulent on the surface, but becomes compact at a depth. It is in some places over a hundred feet in thickness, and is white to brown in color. There often occur in it small lumps containing ammonia salts, and others containing large quantities of phosphate of lime or silica. Gypsum is also abundant in some of the guano beds. The phosphates in the guano occur largely as tricalcic, dicalcic, ammonio-magnesic, and ammonic phosphates, so that a large part of it is in a very soluble rorm, hence its value as plant food. There is also in the guano a soluble base called guanine, with the formula $C_5H_5N_5O$. It will thus be seen that, though some of the ingredients of guano are insoluble, others are very soluble, and, for the preservation of such a deposit a very dry climate is necessary. The coast of Peru is peculiarly adapted to the formation of guano beds, not only on account of the absence of rain, but

[1] Die natürlichen Phosphate.

also on account of the large flocks of sea birds which inhabit the islands along the coast and feed on the vast schools of fish swarming in the surrounding seas.

The first beds that were mined were on the Chincha Islands, off the coast of Peru. The guano of this locality was the richest of all the deposits on the South American coast. The islands are small, rarely more than three miles in circumference, and the beds were practically exhausted as early as 1872. Among the other islands which have been worked and stripped of their valuable deposits are those of Macabi and Guañape, north of the Chincha Islands, as well as those of Ballestas, Lobos, Foca, Pabellon de Pica, Tortuga, Huanillos, and many other islands on the same coast. As will be seen from the analyses, the composition of the guano from these localities varies considerably. It depends on the circumstances under which the deposit was formed, such as the amount of rain, the exposure to the spray of the sea-water, and other conditions.

Though the Peruvian coast is the most important locality for guano, yet it has been obtained in considerable quantities in other places also. It is found near the Cape of Good Hope and northwest of it, at Saldanha Bay. It is also found on the island of Ichaboe, as well as at Algoa Bay, which is on the southern coast of Africa. The guano from these African localities has often been leached by the action of rain and sea water, but it is also found containing large quantities of soluble salts of ammonia and phosphorus. The island of Ichaboe contained 200,000 tons of guano, all of which was removed in fifteen months after its discovery in 1844.

Soluble guano has been found on the Kuria Muria Islands, on the coast of Arabia; at Shark's Bay, Australia, and at many other places in small quantities. The variety known as "bat guano" is generally found in caves, and consists of the dung of bats, mixed with the bodies of their dead, as well as with the remains of rats, mice, etc. Such deposits are of very limited extent. They are found in many places in America and Europe. In the United States bat guano is found in Indiana, Kentucky, Alabama, and many other States. Near San Antonio, Tex., there are several caves containing large quantities of it. It is also found in many places along the coast of the Mediterranean, and especially in Italy.

Analyses of soluble guano.

[I. Mean of 21 analyses of Macabi Island guano, by Barral.]

Nitrogen	10.90
Phosphates	27.60
Potash	2 to 3

[II. Analysis of Macabi guano, by Bobierre.]

Water	30.80
Bone phosphate	35.50
Nitrogen	8.22

[III. Analysis of Guañape Island guano, by Dr. C. U. Shepard, jr.]

Nitrogen	8.20 to 12.80
Phosphoric acid	10.77 to 17.62
Sand and siliceous matter	0.75 to 3.75
Water	11.83 to 29.96

[IV. Average of 22 analyses of Guañape guano, by Barral.]

Nitrogen	10.95
Phosphates	28.00
Potash	2 to 3

[V. Analysis of Guañape guano, by Bobierre.]

Water	24.00
Sand	1.30
Organic matter and ammoniacal salts (1)	37.00
Bone phosphate of lime	36.00
Undetermined matter	1.70
	100.00
(1) Nitrogen	7.75

[VI. Analyses of soluble guanos, by Dehérain.]

	Angamos, coast of Bolivia. White guano.	Bolivian.	Los Patos.	Island of Elide, coast of California.	Îlot de Pedro-Bey, coast of Cuba.
Organic matter	70.21 to 52.92	23.00	32.45	27.37 to 34.50	6.16
Containing nitrogen	20.09 to 14.38	3.38	5.92	1.34 to 6.98	0.28
Equivalent in ammonia	24.36 to 17.44	4.10	7.18	1.62 to 8.46	0.34
Total phosphates	13.30 to 20.95	48.60	34.81	[1] 28.00 to 31.00	48.52

	Mexican coast.	Galapagos, Ecuador.	Falkland Islands.
Organic matter	13.05 to 18.00		17.35 to 28.68
Containing nitrogen	0.21 to 3.45	0.7	0.56 to 2.26
Equivalent in ammonia	0.26 to 4.19	0.85	0.68 to 2.74
Total phosphates	8.00 to 25.00	60.30	[1] 21.46 to 25.62

[1] Containing sometimes very considerable quantities of phosphates of alumina and the oxide of iron.

[VII. Analysis of Peruvian guano by Dr. Ure, Am. Jour. Agric., 1845.]

Uric acid	10.50
Ammonia	19.00
Phosphoric acid	14.00
Lime and magnesia	16.00
Salts of soda and potash	6.00
Oxalic acid, with carbonic and muriatic acids	13.00
Water	13.00
Sand	2.00
Volatile and organic matters	6.50
	100.00

[VIII. Analysis of Peruvian guano, by Nesbit, Agricultural Chemistry, London, 1859.]

Moisture	15.10
Organic matter, etc. (1)	51.27
Silica	2.20
Phosphate of lime	22.13
Phosphoric acid	3.23
Equal to phosphate of lime, 7.00.	
Alkaline salts, etc	6.07
	100.00
(1) Nitrogen	13.54
(1) Ammonia	16.42

[IX. Analysis of Ichaboe guano, Am. Jour. Agric., 1845.]

Ammonia	13.50
Humic acid	4.00
Phosphates	25.00
Oxalic, etc., acids	20.00
Salts of soda, etc	7.00
Water and volatile matter	27.50
Sand	3.00
	100.00

[X. Analyses of soluble guanos, by Nesbit, Agricultural Chemistry.]

	Angamos.		Peruvian.	Chilian.	Bolivian.	Saldanha Bay.	Shark's Bay.
	I.	II.					
Moisture	10.90	12.55	9.30	20.46	16.00	17.92	14.47
Organic matter, etc. (1)	67.36	61.07	57.30	18.50	13.16	14.08	7.85
Sand	1.04	5.36	0.75	22.70	3.16	2.80	14.47
Phosphates	16.10	13.76	23.05	31.00	60.23	59.40	29.54
Alkaline salts, etc	4.60	7.26	9.60	7.54	7.45	5.80	33.67
	100.00	100.00	100.00	100.20	100.00	100.00	100.00
(1) Nitrogen	19.95	18.24	15.54	4.50	2.11	0.63	0.35
(1) Equal to ammonia	24.19	22.12	18.87	5.47	2.56	0.76	0.47

[XI. Analyses of Peruvian guano and of Ichaboe guano; from The Cultivator, vol. 1, 1844.]

	Peruvian guano.	Ichaboe guano.
Water and volatile ammonia	15.27	3.14
Organic matter and ammoniacal salts	51.44	63.52
Chloride and sulphate of soda	5.50	5.02
Insoluble siliceous matter	0.57	1.16
Phosphate of lime and little phosphate of magnesia	21.11	22.20
Carbonates of lime and magnesia	6.11	4.96
	100.00	100.00

[XII. Analyses of soluble guano, by Norton, Elements of Scientific Agriculture, 1860.]

	Bolivian.	Peruvian.	Chilian.	Ichaboe.
Water	5 to 7	7 to 10	10 to 13	18 to 26
Organic matter and ammoniacal salts	56 to 64	56 to 66	50 to 56	36 to 44
Phosphates	25 to 29	16 to 23	22 to 30	21 to 29

[XIII. Analyses of soluble guanos, Cameron, Chemistry of Agriculture.]

	Upper Peruvian.	Ichaboe.	Bird Island.	Cuban.	Kuria Muria.	Patagonian.
Water	10.00	20.00	15.00	26.00	18.10	25.00
Organic matter	21.68	24.40	6.50	4.10	12.41	18.30
Yielding ammonia	(4.50)	(6.00)	....	....	(2.05)	(2.00)
Earthy phosphates	51.50	20.40	37.25	43.70	42.67	44.00
Carbonate of lime	....	....	40.00	24.10	4.19	....
Alkaline salts	14.12	6.20	1.15	....	4.13	2.10
Sand, clay, and other useless matter	2.70	29.00	0.10	2.10	18.50	10.60
	100.00	100.00	100.00	100.00	100.00	100.00

[XIV. Analysis of soluble guano from "an island in the Pacific," by R. S. Burn, Year-Book of Agricultural Facts.]

Water	4.60	4.60
Organic matter and ammoniacal salts	16.85	16.38
Phosphates	71.40	69.90
Carbonate of lime	3.15	7.90
Alkaline salts	3.90	1.07
Sand	0.10	0.15
	100.00	100.00
Ammonia	1.32	1.26

[XV. Analysis of bat guano, Report Indiana Geological Survey, 1879, p. 163.]

Loss at red heat	44.10
Organic matter	4.90
Ammonia	4.25
Silica	6.13
Alumina	14.30
Ferric oxide	1.20
Lime	7.95
Magnesia	1.11
Sulphuric acid	5.21
Carbonic acid	3.77
Phosphoric acid	1.21
Chlorides of alkalies and loss	5.87
	100.00

LEACHED GUANOS.

The second subdivision of guano deposits is leached guano. It is either pulverulent, or in a more or less solidified mass, and consists of guano from which all or almost all the soluble constituents have been dissolved by the action of rain and sea water. It is found most plentifully on some of the small islands in the Pacific Ocean, northeast of Australia, and on many of the West India Islands. It is also found in some places on the coast of Chili, as on the promontory of Mexillones. Here it occurs as a light yellow phosphatic powder, containing lumps of the same substance and averaging 75 to 81 per cent. of bone phosphate of lime.

Leached guano is found in the Pacific principally on the islands lying between longitude 150° to 180° west and latitude 10° N. to 10° S. Most of this area was put by Congress under the protection of the United States in 1856. It contains some forty guano islands. They are all small and low, and are built up by the formation of coral reefs. Often there is a salt-water lagoon in the center of the island. Among the richest localities are Baker, Howland, Jarvis, McKean, Malden, Starbuck, and Phœnix Islands. The guano is generally pulverulent on the top, and more or less solidified below. Occasionally the soluble portions have been washed into the underlying coral, forming a phosphatic limestone. The following is a section on Baker Island:

(1) Pulverulent leached guano, yellow.
(2) Denser stratum of same substance as (1).
(3) Coral rock containing gypsum.

On Jarvis Island a bed of gypsum has been formed by the evaporation of a central lagoon. Overlying this is a deposit of leached guano, from one inch to one foot thick, covered by a phosphatic crust. Under this crust the bed contains both basic and neutral phosphate of lime. This fact is thought by Dr. C. U. Shepard, jr., to be due to the decomposition of the tribasic phosphate by the gypsum. Occasionally concretionary nodules, composed of interstratified layers of phosphate of lime and gypsum, are found. On Malden Island there is a boggy deposit, which gives off sulphureted hydrogen from the mutual decomposition of the guano and the gypsum.

In the West Indies, leached guano has been found on many of the coral islands and reefs, all the way from the Bahamas to the coast of Venezuela. Among the principal localities are Sombrero, Navassa, Turk, St. Martin, Aruba, Curaçoa, Orchillas, Arenas, Roncador, Swan, and Cat, or Guanahani Islands, the Pedro and Morant Keys, and the reefs of Los Monges and Aves in Maracaibo Gulf. The phosphate from the different localities varies very much. That from Maracaibo Gulf occurs in a compact or granular form of a light brown color. Sometimes it is distinctly mammillated, and at other times it has a concentric structure. It often has a white phosphatic enamel like that which covers the basalt of Ascension Island. The deposit contains many fish bones, and is rich in phosphate of lime, which sometimes amounts to over 85 per cent. of the rock. The Sombrero Island phosphate occurs in two forms: (1) As a granular, porous, and friable mass, in color white, pink, green, blue, or yellow; (2) as a dense, massive, and homogeneous deposit of a white or yellow color. It contains 75 to 80 per cent. of phosphate of lime. Many bones occur, and at times the deposit takes the form of a real bone breccia. The principal rock of the island is a palagonite tufa, filled with shells and bones.

The Navassa phosphate is found on an uninhabited island, consisting of a terrace encircled by a high plateau. The phosphate is found in pockets in the living coral, and in the numerous depressions and hollows on the island. It is of a dark brown color, and is composed of a hard mass of oölitic grains. It contains 10 to 15 per cent. of alumina and oxide of iron (Meyn), and is therefore not very popular as a source of superphosphate, as it makes a sticky product.

The phosphate of Aruba Island is of a hard, massive variety, and is white to dark brown in color. Occasionally the underlying coral on this island, as well as on many others in both the West Indies and the Pacific Ocean, has been phosphatized by the infiltration of the soluble parts of the original guano deposits. Thus at Aruba large masses of coral, containing 70 to 75 per cent. phosphate of lime, are found.

Several distinct phosphate minerals occur in pockets in the phosphate beds in the West Indies. One of them, known as pyrophosphorite, was described by Dr. C. U. Shepard, jr., in the American Journal of Science, January, 1878. It is snow white, amorphous, opaque, and has a fracture like magnesite. It has a hardness of 3 to 3.5, and a specific gravity of 2.50 to 2.53. It is essentially an ortho-pyrophosphate of lime with pyrophosphate of magnesia, and has the formula $Mg_2P_2O_7+4(Ca_3P_2O_8, Ca_2P_2O_7)$.

On the islands of Mona and Moneta, in the West Indies, occur the minerals monite and monetite. They were described and named by Prof. C. U. Shepard, sr., in the American Journal of Science, May, 1882. The monetite occurs as a crystalline mineral, of a white or brown color, in association with monite, which is a white, soft, incoherent mass. Monetite is a crystallized dicalcic ortho-phosphate and has the formula $CaHPO_4$. Monite has the formula $Ca_3P_2O_8+H_2O$.

Deposits of leached guano have been found on several islands in the Gulf of California. The deposit on Raza Island averaged over 41 per cent. of phosphoric acid, which corresponds to over 85 per cent. of phosphate of lime. (See analyses.) The beds in this island have been exhausted.

The deposits of the West Indies supply most of the leached guano now sold. Curaçoa annually produces 50,000 to 70,000 tons, and Sombrero about 10,000. The other islands produce much less. The Pacific Ocean islands are, at present, little worked. The difficulty with many of the West India deposits is that they contain large quantities of phosphate of iron and alumina, which make them very undesirable as sources of superphosphate. On some of the islands there occur beds of almost pure phosphate of iron and alumina.

Table of analyses of leached guanos.

[I. Analyses of Baker Island guano (constituents, lumps, crust, coral rock, etc.), by Siegert.]

	(1)	(2)	(3)	(4)	(5)
Water	1.45	10.25	9.03	0.90	8.20
Combustible matter (1)	2.57	5.11	4.02	4.47	8.30
Potash	0.10	0.44	0.43	0.46	0.62
Soda	0.45	0.73	0.62	1.21	1.13
Lime	53.78	43.83	43.44	45.82	40.63
Magnesia	0.27	0.42	0.60	1.89	1.75
Phosphoric acid	0.00	33.97	33.62	38.98	37.16
Sulphuric acid	1.40	2.07	6.81	1.16	1.17
Carbonic acid	39.98	3.18	1.43	5.11	1.04
Total	100.00	100.00	100.00	100.00	100.00
(1) Nitrogen	0.00	0.00	0.00	0.00	0.92

(1) Unchanged coral white rock.
(2) Yellow-brown crust, often several inches thick, with white interior, of coralline structure.
(3) Gray-brown balls, soft to pulverulent, often several inches thick; coralline structure feebly marked.
(4) Porcelain-like cakes, smooth or rough, soft, 1 to 4 inches thick, and in parallel plates.
(5) Whole guano powdered.

[II. Analysis of Howland Island guano, by Drysdale.]

Water	7.20
Combustible matter	14.18
Phosphates	75.32
Sulphate of lime	1.60
Carbonate of lime	1.27
Chloride of alkalies	0.43
Sand	Trace
	100.00

[III. Analyses of Jarvis Island guano, dried at 105 C.]

	Powder.	Lumps.
Water of combination and combustible matter	20.80	18.50
Anhydrous sulphate of lime	30.00	5.00
Phosphates of lime and magnesia	43.20	73.00
Siliceous residue	2.00	1.00
Undetermined ingredients and loss	4.00	2.50
	100.00	100.00

[IV. Analyses of Phœnix Island guano, by Rumpler.]

Water	1.19	2.08
Combustible matter	2.03	5.22
Phosphate of lime	76.00	70.70
Phosphate of magnesia	5.19	13.47
Carbonate of lime	0.68	10.50
Sulphate of lime	0.34	5.10
Nitrogen in the combustible matter	0,39	0.77

[V. Analysis of Aves guano, by Völcker.]

Water	2.39
Organic matter and water of combination	7.93
Lime	39.48
Magnesia	1.17
Phosphoric acid	41.34
Sulphuric acid	4.57
Insoluble siliceous matter	2.28
	99.16
Containing nitrogen	0.139

[VI. Analyses of Navassa phosphate.]

	Gilbert.	Bretschneider.
Water	3.01	3.54
Organic matter and water of combination	7.17	4.64
Lime	40.19	38.35
Magnesia		1.72
Sequioxide of iron	} 11.67	3.40
Alumina		6.50
Potash		0.34
Soda		0.32
Phosphoric acid	33.28	35.60
Sulphuric acid		0.19
Chlorine		0.08
Carbonic acid	2.15	2.58
Silica		1.34
Sand	2.53	1.31
	100.00	99.91

[VII. Analysis of Raza Island phosphate, by Dr. H. Gilbert.]

Water	1.92
Neutral phosphate of lime	58.78
Bone phosphate of lime	18.86
Tribasic phosphate of magnesia	3.32
Sulphate of lime	8.26
Oxide of iron	0.99
Silicic acid	3.38
Organic matter	4.81
	100.32

BONE BEDS.

These deposits include beds which are composed largely of bones.[1] They occur principally as *cave* and *lacustrine* deposits.

CAVE DEPOSITS.

Caverns have always been the places of refuge and the sepulchers of many kinds of animals, and sometimes bones have collected in them in sufficient quantities to form beds many feet thick. Such deposits are

[1] The phosphate beds of South Carolina and other similar deposits do not belong under this heading, for, though many bones occur in them, they are few compared with the accompanying phosphatic nodules.

much larger and more plentiful in Europe than in North America. The reason for this seems to be that in this country there were none of the carnivora, such as the jackals and hyenas, which have the habit of dragging their prey to their lairs. Consequently our caverns, notwithstanding their abundance and the great number of animals which have lived about them, are generally wanting in the extensive osseous breccias which characterize many caves in England, France, Germany, Hungary, Italy, and many other parts of Europe.

Many of the caves of the Southern States have been much resorted to by bats. The excrements of these creatures, together with the bones of those that have died there, have in many cases formed extensive beds of phosphatic and nitrogenous matter.[1] During the early part of this century, and during the civil war, saltpeter was extensively manufactured from them, and some of them have also been worked as a source of phosphate of lime.

LACUSTRINE DEPOSITS.

These deposits occur generally about the swampy margins of salt licks, as at Big Bone Lick in Kentucky[2], and in the ancient lake deposits west of the Mississippi River, as in the Mauvaises Terres of Nebraska. Similar beds are also found in many parts of Europe. The bones found in such localities are the remains of animals which came to the swamps to lick the salt found there, or in search of refuge. Many died natural deaths, while others were mired in the boggy earth, and, being unable to extricate themselves, perished. In this way bones accumulated often in very considerable quantities.

These deposits, as well as those of the cave class, are generally too limited in extent to be of any commercial importance.

[1] These deposits have been described under the heading of Guanos.

[2] An account of this deposit may be found in an appendix to Mr. J. A. Allen's monograph on The History of the Buffalo, in the memoirs of the Kentucky Geological Survey, Vol. I, 1876.

BIBLIOGRAPHY.

A.

Adams (Robert C.). The phosphate industry of Canada.
Canadian Economics, pp. 189-193, 1883.

Alabama:
SMITH. Bull. No. 5, Alabama State Dep. Agric., 1884.
STUBBS. Bull. No. 5, Alabama State Dep. Agric., 1884.

Allen (R. L.). Guano.
A Brief Compendium of American Agriculture, New York, 1847.

Aoust (Virlet d'). Formation des couches de grès par transports moléculaires de la matière du ciment. Formation des nodules de phosphate de chaux par un transport moléculaire de ce dernier.
Bull. Soc. géol. France, xxii, pp. 130-138, 1864-'65.

Austen (Robert Alfred Cloyne). On the position in the Cretaceous series of beds containing phosphate of lime.
Quart. Jour. Geol. Soc. London, iv, pp. 257-262, 1848.

B.

Badouseau (M.). Sur les gisements de chaux phosphatée de l'Estrémadure.
Bull. Soc. cent. agric. France, xxxviii.

Barclay (David). Comparison of guano with other manures.
Jour. Roy. Agric. Soc., 1st ser., vi, pp. 175-176, 1845.

Bartlett (Levi). Discovery of phosphate of lime at Hurdstown, New Jersey.
American Agriculturist, x, pp. 123, 124, 1851.

Belgium:
BOBIERRE. Comp. rend. Acad. sci., lxxiii, pp. 1361-1363, 1871.
BRIART and CORNET. Bull. Acad. roy. Belg., 2e sér., xxii, pp. 329-339, 1866.
—— Bull. Acad. roy. Belg., 2e sér., xxxvii, pp. 838-841, 1874.
CORNET. Bull. Soc. géol. France, 3e sér., ii, pp. 567-577, 1873-'74.
—— Quart. Jour. Geol. Soc. London, xlii, pp. 325-340, 1886.
—— See Briart and Cornet.

Belgium—Continued.
LAMBERT. Bull. Acad. roy. Belg., 2e sér., xxix, pp. 254-259, 1870.
MELSENS. Bull. Acad. roy. Belg., 2e sér., xxxviii, pp. 23-35, 1874.
NIVOIT. Compt. rend. Acad. sci., lxxix, pp. 256-259, 1874.
—— Assoc. franç. avanc. sci., 4e session, pp. 662-676, 1875.
PETERMANN. Bull. Acad. roy. Belg., 2e sér., xxxviii, p. 652, 1874.
—— Bull. Acad. roy. Belg., 2e sér., xxxix, pp. 12-13, 1875.
—— Bull. Acad. roy. Belg., 2e sér., xlv, p. 3, 1878.
SHEPARD. Foreign Phosphates, Charleston, 1879.

Bell (Alfred). The succession of the Crags.
Geol. Mag., ix, pp. 209-215, London, 1872.

Bell (Robert). On the mode of occurrence of apatite in Canada.
Eng. and Mining Jour., xxxix, p. 316.

Bigsby (John Jeremiah). On the Laurentian formation.
Geol. Mag., i, pp. 154-158, 200-206, London, 1864.

Blanchère (H. de la). Phosphates de chaux et usines de Bellegarde.
Jour. agric. prat., pp. 630-632, 1873.

Bobierre (Adolphe). Sur la composition de la chaux phosphatée récemment exploitée dans les départements de Tarn-et-Garonne et du Lot.
Compt. rend. Acad. sci., lxxiii, pp. 1361-1363, 1871.
—— Chimie agricole. Paris, 1872.
—— Contrôle des engrais dans la Loire-Inférieure.
Jour. agric. prat., pp. 120-124, 1873.

Bonney (Thomas George). On the chloritic marl or Upper Greensand of the neighborhood of Cambridge.
Geol. Mag., ix, pp. 143-144, London, 1872.

Bordet (H.). Phosphates fossiles trouvés dans un minerai de fer.
Jour. agric. prat., p. 11, 1873.

Briart (Alph.) and F. L. Cornet. Note sur l'existence, dans l'Entre-Sambre et Meuse, d'un dépôt contemporain du système du tuffeau de Mæstricht et sur l'âge des autres couches crétacées de cette pàrtie du pays.

Briart—Continued.

Bull. Acad. roy. Belg., 2e sér., xxii, pp. 329-339, 1866.

——— Notice sur les gisements de phosphate de chaux dans le terrain crétacé de la province de Hainaut.

Bull. Acad. roy. Belg., 2e sér., xxxvii, pp. 838-841, 1874.

Brodie (Peter Bellenger). On a deposit of phosphatic nodules in the Lower Greensand at Sandy, Bedfordshire.

Geol. Mag., iii, pp. 153-155, London, 1866.

Brögger (W. C.). and H. H. Reusch. Vorkommen des Apatits in Norwegen.

Zeitsch. Deutsch. geol. Gesell., xxvii, pp. 646-702, 1875.

Broome (Gordon). Canadian phosphates considered with reference to their use in agriculture.

Canadian Naturalist, v, pp. 241-263, 1870.

——— On the phosphate of lime and mica found in North and South Burgess and North Elmsley (Ontario).

Geol. Surv. Canada, Rep. Prog., 1870-'71, pp. 316-320.

Buckland (William). On the causes of the general presence of phosphates in the strata of the earth and in all fertile soils.

Jour. Roy. Agric. Soc., 1st ser., x, pp. 520-525, 1843.

——— On the discovery of a new species of pterodactyl; and also of the fæces of the Ichthyosaurus and of a black substance resembling sepia or India ink, in the Lias at Lyme Regis.

Geol. Soc. Proc., i, pp. 96-98, 142-143, 1834.

——— On the occurrence of nodules (called petrified potatoes) found on the shores of Lough Neagh in Ireland.

Quart. Jour. Geol. Soc. London, ii, pp. 103-104, 1846.

——— On the discovery of coprolites or fossil fæces in the Lias at Lyme Regis, and in other formations.

Trans. Geol. Soc. London, 2d ser., iii, pp. 223, 235.

Burn (R. Scott). Guano.

Year Book of Agricultural Facts, 1859.

C.

Caillaux (Alfred). Origine des phosphates de chaux.

Jour. agric. prat., pp. 310-314, 1874.

Calderon (M.). Note sur les phosphorites nouvellement découvertes dans le midi de l'Espagne.

Bull. Soc. géol. France, 3e sér., vii, pp. 11-13, 1878-'79.

Cameron (C. A.). Guanos.

Chemistry of Agriculture, Dublin, 1857.

Canada:

ADAMS. Canadian Economics, pp. 189-193, 1883.

BELL. Eng. and Mining Jour., xxxix, p. 316.

BIGSBY. Geol. Mag., pp. 154, 200, London, 1864.

BROOME. Canadian Nat., v, pp. 241-263, 1870.

——— Geol. Surv. Canada, Rep. Prog., 1870-'71, pp. 316-320.

DAWKINS. Trans. Manchester Geol. Soc., 1884.

DAWSON. Quart. Jour. Geol. Soc. London, xxxii, p. 285, 1876.

HARRINGTON. Geol. Surv. Canada, Rep. Prog., 1877-'78, pp. 1G-50G.

HOFFMANN. Geol. Surv. Canada, Rep. Prog., 1877-'78, pp. 1H-14H.

HUNT. Geol. Surv. Canada, Rep. Prog., 1851-'52, p. 106.

——— Quart. Jour. Geol. Soc., viii, p. 209, 1852.

——— Geol. Surv. Canada, Rep. Prog., pp. 202-204 and 224-229, 1863-'66.

——— Report on Deposits of Phosphate of Lime on the Property of Messrs. Osborne, Bell, and Claxton, Ottawa.

——— Trans. Am. Inst. Mining Eng., xii, pp. 459-468, 1883-'84.

——— Trans. Am. Inst. Mining Eng., xiv, pp. 495-496, 1885-'86.

LOGAN. Geol. Surv. Canada, Rep. Prog., 1852, pp. 28-33.

——— Geol. Surv. Canada, Rep. Prog., 1858, p. 64.

——— Geol. Surv. Canada, Rep. Prog., 1863, pp. 125, 460-463, 757-761.

RICHARDSON. Geol. Surv. Canada, Rep. Prog., 1866-'69, p. 125.

SHEPARD. Foreign Phosphates, Charleston, 1879.

VENNOR. Geol. Surv. Canada, Rep. Prog., 1870-'71, pp. 314, 315.

——— Geol. Surv. Canada, Rep. Prog., 1871-'72, pp. 123-129.

——— Geol. Surv. Canada, Rep. Prog., 1872-'73, pp. 136-179.

——— Geol. Surv. Canada, Rep. Prog., 1873-'74, pp. 107-145.

——— Geol. Surv. Canada, Rep. Prog., 1874-'75, pp. 105-165.

——— Geol. Surv. Canada, Rep. Prog., 1876-'77, pp. 301-308.

——— Géologie du Canada, 1876-'77, pp. 343-363.

Céris (A. de). Gisement de phosphate de chaux à l'île de Sombrero.
Jour. agric. prat., 763, 1868.

——— Découverte de nouveaux gisements de phosphate de chaux en France.
Jour. ágric. prat., p. 143, 1869.

——— Gisements de phosphates de chaux dans les départements de Tarn-et-Garonne et du Lot.
Jour. agric. prat., 2e sér., p. 1216, 1870–'71.

——— Gisement de phosphate dans la Caroline du Sud.
Jour. agric. prat., p. 1327, 1870–'71.

Charlesworth (Edward). On the prospective annihilation of the Suffolk Red Crag as a geological formation, with a few remarks about the Red Crag phosphatic stones, "Coprolite."
Geol. Mag., v, pp. 577–580, London, 1868.

Chevreul (Michel Eugène). Communications sur le guano du Pérou.
Compt. rend. Acad. sci., lxxvi, pp. 1285, 1313, 1376–1383, 1505–1508, 1873.

Clarke (J. A.). Guanos.
Jour. Roy. Agric. Soc., 2d ser., xiv, p. 357.

Collenot (M.). Du phosphate de chaux dans l'Auxois.
Bull. Soc. géol. France, 3e sér., v, pp. 671–687, 1876–'77.

Convert (F.). Les phosphates de Bellegarde.
Jour. agric. prat., pp. 405–408, 1873.

Cook (George H.). Canfield's phosphate of lime and iron-ore bed.
Ann. Rep. Geol. New Jersey, pp. 34–38, 1871.

Cornet (F. L.). Compte rendu de l'excursion du 31 août aux environs de Ciply.
Bull. Soc. géol. France, 3e sér., ii, pp. 567–577, 1873–'74.

——— On the upper Cretaceous series and the phosphatic beds in the neighborhood of Mons (Belgium).
Quart. Jour. Geol. Soc., xlii, pp. 325–340, 1886.

——— See, also, Briart (Alph.) and F. L. Cornet.

Courtois (C.). Les phosphates de la Côte-d'Or.
Jour. agric. prat., pp. 594–599, 1878.

Cox (Edward T.). Bat Guano.
Geol. Surv. Indiana for 1878, pp. 163, 164, 1879.

D.

Dabney (Charles W.). North Carolina phosphates.
Rep. North Carolina Agric. Exp. Sta., pp. 57–83, 1883.

Damour (Augustin Alexis). Phosphates d'Yttria du Brésil.
Bull. Soc. géol. France, 2e sér., xiii, pp. 548–549, 1855–'56.

Dana (James Dwight). Guano Deposits.
Corals and Coral Islands, New York, p. 283, 1872; pp. 291–297, ed. 1885.

Daubeny (Charles) and S. E. Widdrington. On the occurrence of phosphorite in Estremadura.
Jour. Roy. Agric. Soc., 1st ser., v, pp. 406–418, 1845.

——— On the occurrence of phosphorite in Estremadura.
Quart. Jour. Geol. Soc. London, i, pp. 52–55, 1845.

Daubrée (Auguste). Notice sur la découverte et la mise en exploitation de nouveaux gisements de chaux phosphatée.
Ann. Mines, 6e sér., xiii, pp. 67–95, 1868.

——— Gisement dans lequel la chaux phosphatée a été récemment découverte dans les départements de Tarn-et-Garonne et du Lot.
Compt. rend. Acad. sci., lxxiii, pp. 1028–1036, 1871.

——— Gisement dans lequel la chaux phosphatée a été récemment découverte dans les départements de Tarn-et-Garonne et du Lot.
Compt. rend. Acad. sci., lxxiv, pp. 1372–1373, 1872.

Davies (D. C.). On a bed of phosphate of lime northwest of Llanfyllin, North Wales.
Geol. Mag., iv, pp. 251–253, London, 1867.

——— The deposits of phosphate of lime recently discovered in Nassau, North Germany.
Geol. Mag., v, pp. 262–266, London, 1868.

——— The phosphorite deposits of North Walès.
Geol. Mag., xii, p. 183, London, 1875.

——— The phosphorite deposits of North Wales.
Quart. Jour. Geol. Soc. London, xxxi, pp. 357–367, 1875.

Dawkins (William Boyd). On some deposits of apatite near Ottawa, Canada.

Trans. Manchester Geol. Soc. (1884), vol. 18, 1886.

Dawson (John William). Note on the phosphates of the Laurentian and Cambrian rocks.

Quart. Jour. Geol. Soc. London, xxxii, p. 285, 1876.

Donaldson (John). Guano in soils and manures.

Duffield (A. J.). Peru in the Guano Age. London: Bentley & Son, 1877.

——— The Prospects of Peru. London: Newman, 1881.

E.

Egozcue (D. J.) and D. L. Mallada. Descripcion de los criaderos de fosforita.

Mem. de la Comision del mapa geológico de España, pp. 184–300, 1876.

Eights (James). Origin of guano.

The Cultivator, i, pp. 379–380, 1844.

Emmons (Ebenezer). Discovery of an immense vein of phosphate of lime.

American Agriculturist, x, pp. 81, 82, 1851.

England:

AUSTEN. Quart. Jour. Geol. Soc., iv, pp. 257–262, 1848.

BELL, A. Geol. Mag., ix, pp. 209–215, London, 1872.

BONNEY. Geol. Mag., ix, pp. 143–144, London, 1872.

BRODIE. Geol. Mag., iii, pp. 153–155, London, 1866.

BUCKLAND. Geol. Soc. Proc., i, pp. 96–98, 1834.

——— Quart. Jour. Geol. Soc. London, ii, pp. 103, 104, 1846.

——— Trans. Geol. Soc. London, 2d ser., iii, pp. 223–235.

CHARLESWORTH. Geol. Mag., v, pp. 577–580, London, 1868.

FISHER. Geol. Mag., viii, pp. 65–71, London, 1871.

——— Quart. Jour. Geol. Soc. London, xxviii, pp. 396–397, 1872.

——— Quart. Jour. Geol. Soc. London, xxix, pp. 52–62, 1873.

FITTON. Trans. Geol. Soc. London, 2d ser., iv, pp. 103–378, 1835.

——— Quart. Jour. Geol. Soc. London, iii, pp. 289–327, 1847.

HENSLOW. Brit. Assoc. Adv. Sci., notices and abstracts, 15th meeting, pp. 51–52, 1845.

HERAPATH. Jour. Roy. Agric. Soc., 1st ser., xii, pp. 91–105, 1851.

HICKS. Quart. Jour. Geol. Soc., xxxi, pp. 368–383, 1875.

England—Continued.

——— Quart. Jour. Geol. Soc., xlii, pp. 3–19, 1886.

JENYNS. Geol. Mag., iii, pp. 307–308, London, 1866.

——— Bath Nat. Hist. Club, 1867.

JUDD. Quart. Jour. Geol. Soc., xxiv, pp. 218–249, 1868.

——— Quart. Jour. Geol. Soc., xxvi, pp. 326–348, 1870.

JUKES-BROWNE and SOLLAS. Quart. Jour. Geol. Soc. London, xxix, pp. 11–15, 1873.

KEEPING, H. Geol. Mag., pp. 272, 273, London, 1868.

KEEPING, W. Geol. Mag., pp. 372–375, London, 1875.

——— Neocomian Fossils of Upware and Brickhill.

LANKESTER. Geol. Mag., pp. 103–106, 149–152, London, 1865.

MANTELL. Medals of Creation, i, p. 432.

MARR. Geol. Mag., pp. 268, 269, London, 1876.

NESBIT. Quart. Jour. Geol. Soc. London, iv, p. 262, 1848.

PAINE and WAY. Jour. Roy. Agric. Soc., 1st ser., ix, pp. 56–84, 1848.

PENNINGTON. Geol. Mag., ii, n. s., pp. 184, 185, London, 1875.

PRESTWICH. Quart. Jour. Geol. Soc. London, xxvi, pp. 281, 282, 1870.

——— Quart. Jour. Geol. Soc. London, xxvii, pp. 115–146, 1871.

R. (C. E.) Geol. Mag., ii, p. 527, London, 1865.

SEELEY. Ann. Mag. Nat. Hist., xvii, pp. 173–183, 1866.

——— Geol. Mag., iii, pp. 302–307, London, 1866.

SHEPARD. Foreign Phosphates, Charleston, S. C., 1879.

SOLLAS. Quart. Jour. Geol. Soc. London, xxviii, pp. 397–400, 1872.

——— Geol. Mag., x, p. 92, London, 1873.

——— Geol. Mag., x, pp. 268–274, London, 1873.

——— Quart. Jour. Geol. Soc. London, xxix, pp. 76–81, 1873.

——— Geol. Mag., pp. 539–544, London, 1876.

——— and Jukes-Browne. Quart. Jour. Geol. Soc. London, xxix, pp. 11–15, 1873.

VÖLCKER. Jour. Roy. Agric. Soc., 2d ser., xxi, pp. 350–381, 1860.

W[ALKER], J. F. Geol. Mag., n. s., iii, pp. 41–43, London, 1876.

WALKER. Ann. Mag. Nat. Hist., 3d ser., xviii, pp. 381–386, 1866.

——— Ann. Mag. Nat. Hist., 3d ser., xx, pp. 118–121, 1867.

——— Geol. Mag, iv, pp. 309–310, London, 1867.

——— Geol. Mag., v, pp. 26–27, London, 1868.

——— Monog. Trigoniæ, Palæontographical Soc., xxix, p. 145, 1875.

WAY and PAINE. Jour. Roy. Agric. Soc., 1st ser., ix, pp. 56–84, 1848.

WOOD. Geol. Mag., iii, p. 371, London, 1866.

WOODWARD. Geol. Mag., i, pp. 112–114, London, 1864.

F.

Filhol (Henri). Recherches sur les phosphorites du Quercy. Étude des fossiles qu'on y rencontre et spécialement des mammifères.
Ann. sci. géol., Paris, vii, pp. 1-220, 1876.

Fisher (Osmond). On phenomena connected with denudation observed in the so-called coprolite pits near Haslingfield, Cambridgeshire.
Geol. Mag., viii, pp. 65-71, London, 1871.

——— On the phosphatic nodules of the Cretaceous rock of Cambridgeshire.
Quart. Jour. Geol. Soc. London, xxviii, pp. 396-397, 1872.

——— On the phosphatic nodules of the Cretaceous rock of Cambridgeshire.
Quart. Jour. Geol. Soc. London, xxix, pp. 52-62, 1873.

Fitton (William Henry). Observations on some of the strata between the Chalk and the Oxford Oölite in the southeast of England.
Trans. Geol. Soc, 2d ser., iv, pp. 103-378, 1835.

——— A stratigraphical account of the section from Atherfield to Rocken End, on the southwest coast of the Isle of Wight.
Quart. Jour. Geol. Soc., iii, pp. 289-327, 1847.

France:

AOUST. Bull. Soc. géol. France, xxii, pp. 130-138, 1864-'65.

BLANCHÈRE. Jour. agric. prat., pp. 630-632, 1873.

BOBIERRE. Jour. agric. prat., pp. 120-124, 1878.

BORDET. Jour. agric. prat., p. 11, 1873.

CAILLAUX. Jour. agric. prat., pp. 310-314, 1874.

CÉRIS, A. de. Jour. agric. prat., p. 143, 1869.

——— Jour. agric. prat., p. 1216, 1870-'71.

COLLENOT. Bull. Soc. géol. France, 3e sér., v, pp. 671-687, 1876-'77.

CONVERT. Jour. agric. prat., pp. 405-408, 1873.

COURTOIS. Jour. agric. prat., pp. 594-599, 1878.

DAUBRÉE. Ann. mines, 6e sér., xiii, pp. 67-95, 1868.

——— Compt. rend. Acad. sci., lxxiii, pp. 1028-1036, 1871.

——— Compt. rend. Acad. sci., lxxiv, pp. 1372-1373, 1872.

FILHOL. Ann. sci. géol., vii, pp. 1-220, 1876.

G., C. Jour. agric. prat., p. 700, 1882.

GEORGE. Jour. agric. prat., pp. 818-820, 1872.

GERVAIS. Jour. zoologie, i, pp 261-268, 1872.

France—Continued.

Grossomore. Bull. Soc. géol. France, 3e sér., vi, pp. 315-317, 1877-'78.

GRUNER. Bull. Soc. géol. France, xxviii, pp. 62-72, 1870-71.

JAILLE. Jour. agric. prat., 530, 1873.

KUHLMANN. Compt. rend. Acad. sci., lxxv, pp. 1678-1681, 1872.

LORY. Assoc. franç. avanc. sci., 4e session, p. 676, 1875.

MARTIN. Bull. Soc. géol. France, 3e sér., iii, pp. 273-281, 1874-'75.

MÉRICE. Jour. agric. prat., pp. 728-730, 1876.

MEUGY. Bull. Soc. géol. France, 2e sér., xiii, pp. 604-605, 1855-'56.

——— Ann. mines, 5e sér., xi, pp. 149-176, 1857.

MIDI. Les gisements de phosphate de chaux du, Jour. agric. prat., pp. 307-309, 1872.

NIVOIT. Assoc. franç. avanc. sci., 4e session, pp. 662-676, 1875.

——— Bull. Soc. géol. France, 3e sér., viii, pp. 357-365, 1879-'80.

PERON. Bull. Soc. géol. France, 3e sér., ii, pp. 108-120, 1873-'74.

REY-LESCURE. Bull. Soc. géol. France, 3e sér., iii, p. 398-418, 1874-'75.

SHEPARD. Foreign Phosphates, Charleston, S. C., 1879.

VILLENEUVE. Bull. Soc géol. France, 2e sér., x, pp. 631-634, 1852-'53.

G.

G (C,), Phosphates des Ardennes.
Jour. agric. prat., p. 700, 1882.

Gardner (D. P.). Analyses of guanos.
The Cultivator, i, pp. 291-292, 1844.

George (Hector). Les phosphates de chaux du Quercy.
Jour. agric. prat., pp. 818-820, 1872.

Germany:

DAVIES. Geol. Mag., v, pp. 262-266, London, 1868.

GRÜNEBERG. Jour. agric. prat., p. 344, 1869.

NAUMANN. Elemente der Mineralogie, Leipzig 1859.

SHEPARD. Foreign phosphates, Charleston, S. C., 1879.

VÖLCKER. Jour. Roy. Agric. Soc., 1st ser., xxi, p. 350, 1860.

Gervais (Paul). Sur les mammifères dont les ossements accompagnent les dépôts de chaux phosphatée des départements de Tarn-et-Garonne et du Lot.
Jour. zoologie, i, pp. 261-268, 1872.

Grossonore (A. de). Note sur un nouveau gisement de phosphate de chaux.
Bull. Soc. géol. France, 2e sér., vi, pp. 315-317, 1877-'78.

Grüneberg (H.). Phosphorite du Nassau.
Jour. agric. prat., p. 344, 1869.

Gruner (Emm. L.). Note sur les nodules phosphatés de la Perte du Rhône.
Bull. Soc. géol. France, xxviii, pp. 62–72, 1870–'71.

Guano:
ALLEN. Compendium of American Agriculture, New York, 1847.
BARCLAY. Jour. Roy. Agric. Soc., 1st ser., vi, pp. 175–176, 1845.
BOBIERRE. Chimie agricole, Paris, 1872.
BURN. Year Book of Agricultural Facts, 1859.
CAMERON. Chemistry of Agriculture, Dublin, 1857.
CÉRIS. Jour. agric. prat., p. 763, 1868.
CHEVREUL. Compt. rend. Acad. sci., lxxvi, pp. 1285, 1313, 1376–1383, 1505–1508, 1873.
CLARKE. Jour. Roy. Agric. Soc., 2d ser., xiv, p. 357.
COX. Geol. Surv. Indiana, pp. 163–164, 1879.
DAMOUR. Bull. Soc. géol. France, 2e sér., xiii, pp. 548–549, 1855–'56.
DANA. Corals and Coral Islands, p. 283, New York, 1872.
DONALDSON. Soils and Manures.
DUFFIELD. Peru in the Guano Age. London: Bentley & Son, 1877.
——— The Prospects of Peru. London: Newman, 1881.
EIGHTS. The Cultivator, i, pp. 379–380, 1844.
GARDNER. The Cultivator, i, pp. 291–292, 1844.
HAGUE. Am. Jour. Sci., 2d ser., xxxiv, pp. 224–243, 1862.
HOBSON, HURTADO & CO. Facts Respecting Peruvian Guano, New York, 1870.
——— Peruvian Guano, New York, 1877.
HUDSON. Jour. Roy. Agric. Soc., 1st ser., xii, pp. 249–255, 1851.
HUGHES. Quart. Jour. Geol. Soc. London, xli, pp. 80–81, 1885.
JOHNSTON. Jour. Roy. Agric. Soc., 1st ser., ii, pp. 301–321, 1841.
MÉRICE. Jour. agric. prat., pp. 728–730, 1876.
MEYN. Die natürlichen Phosphate, Leipzig, 1873.
MURCHISON. Jour. Roy. Agric. Soc., 1st ser., xx, p. 31.
NESBIT. Properties of Peruvian Guano, London, 1859.
NORTON. The Cultivator, i, pp. 245, 364, 1844.
——— Elements of Scientific Agriculture, New York, 1860.
SHARPLES. Bost. Soc. Nat. Hist. Proc., xxii, pp. 242–253, 1882–'83.
SHEPARD, C. U., jr. Foreign Phosphates, Charleston, S. C., 1879.
SHEPARD, C. U., sr. Rural Carolinian, May, 1870; April, 1872.
ST. JOHN. British commercial reports, lxxii, pp. 525–537, 1878.

Guano—Continued.
TESCHERMACHER. Am. Agriculturist, pp. 23–25, 334–335, 1844.
——— Essay on Guano.
THAER. Principles of Agriculture, New York, 1846.
URE. Jour. Roy. Agric. Soc., 1st ser., v, pp. 287–306, 1845.
VÖLCKER. Jour. Roy. Agric. Soc., 2d ser., iv, No. vii, pt. 1, pp. 176–196, 1868.
——— Jour. Roy. Agric. Soc., 2d ser., vi, No. xii, pt. 1, p. 142, 1870.
——— Jour. Roy. Agric. Soc., 2d ser., vi, No. xii, pt. 2, pp. 415–424, 1870.
——— Jour. Roy. Agric. Soc., 2d ser., viii, No. xv, pt. 1, p. 220, 1872.
——— Jour. Roy. Agric. Soc., 2d ser., ix, No. xvii, pt. 1, p. 261, 1873.
——— Jour. Roy. Agric. Soc., 2d ser., xi, No. xxii, pt. 2, p. 349, 1875.
——— On Phosphatic Guanos, London, Clowes & Sons, 1876.
——— Roy. Agric. Soc. Report xii, pt. 2, pp. 440–459, 1876.
——— Jour. Roy. Agric. Soc., 2d ser., xiii, No. xxv, pt. 1, p. 189, 1877.
——— Jour. Roy. Agric. Soc., 2d ser., xiv, No. xxvii, pt. 1, pp. 246–255, 1878.
——— Jour. Roy. Agric. Soc., 2d ser., xv, No. xxix, pt. 1, pp. 346–352, 1879.
——— Jour. Roy. Agric. Soc., 2d ser., xvi, No. xxxi, pt. 1, pp. 311–321, 1880.
——— Jour. Roy. Agric. Soc., 2d ser., xvii, No. xxxiii, pt. 1, pp. 291–299, 1881.
——— Jour. Roy. Agric. Soc., 2d ser., xviii, No. xxxv, pt. 1, pp. 333–345, 1882.
——— Jour. Roy. Agric. Soc., 2d ser., xix, No. xxxvii, pt. 1, pp. 245–247, 1883.
WAY. Jour. Roy. Agric. Soc., 1st ser., x, pp. 196–230, 1849.

Guerard (Arthur R.). An essay on application of finely ground mineral phosphate of lime and "ash-element" as manures.
Charleston, S. C., News-Courier book presses, 1882.

H.

Hague (J. D.). On the phosphatic guano islands of the Pacific Ocean.
Am. Jour. Sci., 2d ser., xxxiv, pp. 224–243, 1862.

Harrington (B. J.). Report on the minerals of some of the apatite-bearing veins of Ottawa County, Quebec.
Geol. Surv. Canada, Rep. Prog., 1877–'78, pp. 1G–50G.

Henslow (John Stevens). On nodules, apparently coprolitic, from the

Henslow—Continued.
Red Crag, London Clay, and Greensand.
Rep. Brit. Assoc. Adv. Sci., pp. 51, 52, notices and abstracts, 15th meeting, 1845.

Herapath (Thornton John). Some observations on the chemical composition and agricultural value of the fossil bones and pseudo-coprolites of the Crag.
Jour. Roy. Agric. Soc., 1st ser., xii, pp. 91-105, 1851.

Hicks (Henry). On the occurrence of phosphates in the Cambrian rocks. (Analyses by Huddleston, W. H.)
Quart. Jour. Geol. Soc. London, xxxi, pp. 368-376, 1875.

——— Results of recent research in some bone-caves in North Wales (Flynnon Beuno and Cae Gwyn).
Quart. Jour. Geol. Soc. London, xlii, pp. 3-16, 1886.

Hitchcock (Edward). Occurrence of phosphate of lime in Massachusetts.
Geol. of Massachusetts, pp. 310, 343, 396, 502, 1833.

Hitchcock (Charles H.). Natural fertilizers of New Hampshire.
Geol. of New Hampshire, iii, pt. 5, 94-95, 1878.

Hobson, Hurtado & Co. Facts Respecting Peruvian Guano. New York, 1870.

——— Peruvian Guano. New York, 1877.

Hoffmann (Christian). Chemical contributions to the geology of Canada. On Canadian apatite.
Geol. Surv. Canada, Rep. Prog., 1877-'78, pp. 1H-14H.

Holmes (Francis S.). Phosphate Rocks of South Carolina and the Great Carolina Marl Bed, Charleston, S. C., 1872.

Hudson (James). On American phosphate of lime.
Jour. Roy. Agric. Soc., 1st ser., xii, pp. 249-255, 1851.

Hughes (George). On some West Indian phosphates.
Quart. Jour. Geol. Soc. London, xli, pp. 80-81, 1885.

Hunt (Thomas Sterry). Black phosphatic nodules at R. Ouelle, in a calcareous conglomerate, Lower Canada.
Geol. Surv. Canada, Rep. Prog., 1851-'52, p. 106.

Hunt—Continued.
——— Examination of phosphatic matters, supposed bones, and coprolites, occurring in the Lower Silurian rocks of Canada.
Quart. Jour. Geol. Soc., viii, p. 209, 1852.

——— Apatite.
Geol. Surv. Canada, Rep. Prog., 1863-'66, pp. 202-204; 224-229.

——— A report upon the deposits of phosphate of lime on the property of Messrs. Osborne, Bell and Claxton. Ottawa.

——— The apatite deposits of Canada.
Trans. Am. Inst. Mining Eng., xii, pp. 459-468, 1883-'84.

——— Note on the apatite region of Canada.
Trans. Amer. Inst. Mining Eng., xiv, pp. 495-496, 1885-'86.

I.

Indiana:
Cox. Geol. Survey Indiana, pp. 163-164 (1879).

J.

Jackson (Charles T.). Phosphates in New Hampshire.
Final Rep. Geol. of New Hampshire, p. 115, 1844.

——— Crystal of phosphorite from Hurdstown, N. J. (Analysis.)
Am. Jour. Sci., 2d ser., xi, pp. 402, 403, 1851.

Jaille (Alexandre). Phosphates du Midi et les phosphates des Ardennes.
Jour. agric. prat., ii, p. 530, 1873.

Jenyns (Leonard). Phosphatic nodules.
Geol. Mag., iii, pp. 307, 308, London, 1866.

——— Phosphatic nodules of the eastern counties.
Proc. Bath Nat. Hist. Club, i, part 1, pp. 8-23, 1867-'69.

Johnson (M. Hawkins). Note on the structure of the phosphatic nodules from the top of the Bala limestone in North Wales.
Geol. Mag., n. s., ii, p. 238, London, 1875.

Johnston (James F. W.). Deposits of guano along the Peruvian coast.
Jour. Roy. Agric. Soc., 1st ser., ii, pp. 301-302, 1841.

Judd (John W.). On the Speeton clay.
Quart. Jour. Geol. Soc. London, xxiv, pp. 218-249, 1868.

——— On the Neocomian strata of Yorkshire and Lincolnshire.
Quart. Jour. Geol. Soc. London, xxvi, pp. 326-348, 1870.

Jukes-Browne (Alfred J.) and W. Johnson Sollas. On the included rock fragments of the Cambridge Upper Greensand.
Quart. Jour. Geol. Soc. London, xxix, pp. 11-15, 1873.

K.

Keeping (H.). Discovery of Gault with phosphatic stratum at Upware.
Geol. Mag, v, pp. 272, 273, London, 1868.

Keeping (Walter). On the occurrence of Neocomian sands with phosphatic nodules at Brickhill, Bedfordshire.
Geol. Mag., n. s., ii, pp. 372-375, London, 1875.

——— The fossils and palæontological affinities of the Neocomian deposits of Upware and Brickhill.

Kentucky:
SHALER. Geol. Surv. Kentucky, n. s., iv, pp. 18-65, 1878.

König (Joseph). Einfluss einiger Ammonsalze auf die Fällung der Phosphorsäure durch molybdänsaures Ammon.
Zeitschr. anal. Chemie, pp. 305-307, 1871.

Kuhlmann (Fréd.). Recherche du brome et de l'iode dans les phosphates calcaires.
Compt. rend. Acad. sci., lxxv, pp. 1678-1681, 1872.

L.

Lambert (Gustave). Découverte d'un gisement de phosphate de chaux au-dessous de la ville de Louvain.
Bull. Acad. roy. Belg., 2e sér., xxix, pp. 254-259, 1870.

Lankester (E. Ray). On the Crags of Suffolk and Antwerp.
Geol. Mag., pp. 103-106, 149-152, London, 1865.

Leidy (Joseph). Description of vertebrate remains, chiefly from the phosphate beds of South Carolina.
Jour. Acad. Nat. Sci. Phila., 2d ser., viii, pp. 209-262, 1874-1881.

Logan (*Sir* William Edmond). Phosphate of lime.
Geol. Surv. Canada, Rep. Prog , 1851-'52, pp. 28-33.

——— Phosphate of lime.
Geol. Surv. Canada, Rep. Prog., 1858, p. 64.

——— Phosphate of lime.
Geol. Surv. Canada, Rep. Prog., 1863, pp. 125, 460-463, 757-761.

Lory (Charles). Les gisements de phosphate du sud-est de la France.
Assoc. franç. avanc. sci., 4e session, p. 676, 1875.

Luna (Ramon de). Sur des gisements considérables de phosphate de chaux dans l'Estrémadure.
Compt. rend. Acad. sci., lxi, pp. 47-52, 1865.

——— On considerable deposits of phosphate of lime at Cáceres, Estremadura.
Geol. Mag., ii, p. 446, London, 1865.

——— Sur un gisement de phosphate de chaux découverte dans l'Estrémadure.
Compt. rend. Acad. sci., lxiii, pp. 220-221, 1866.

Luna (Ramon Torres Muñoz de). Estudios químicos sobre economía agrícola en general, y particularmente sobre la importancia de los abonos fosfatados. Madrid, 1868.

M.

Mallada (D. L.). See Egozcue (D. J.) and D. L. Mallada.

Mantell (Gideon Algernon). Molluskite.
Medals of Creation, i, p. 432.

Marr (J. E.). Note on the occurrence of phosphatized carbonate of lime at Cave Ha, Yorkshire.
Geol. Mag., n. s., iii, pp. 268-269, London, 1876.

Martin (Jules). Des nodules phosphatés du Gault et de la Côte-d'Or et des conditions particulières du dépôt de cet étage.
Bull. Soc. géol. France, 3e sér., iii, pp. 273-280, 1874-'75.

Massachusetts:
HITCHCOCK. Geol. of Massachusetts, pp. 310, 343, 396, 502, 1833.

Melsens (H. Louis F.). Note sur l'importance du gisement de phosphate de chaux des environs de Ciply (Province de Hainaut).
Bull. Acad. roy. Belg., 2e sér., xxxviii, pp. 23-35, 1874.

Mérice (E.). Phosphates et guanos.
Jour. agric. prat., pp. 728-730, 1876.

Meugy (A.). Phosphate de chaux en nodules dans la craie de Rethel (Ardennes).
Bull. Soc. géol. France, 2e sér., xiii, pp. 604-605, 1855-'56.

Meugy—Continued.

——— Mémoire sur la découverte des phosphates de chaux terreux en France et sur l'emploi de cet engrais dans la culture.
Ann. mines, 5e sér., xi, pp. 149-176, 1857.

Meyn (L.). Die natürlichen Phosphate. Leipzig, 1873.

Midi, les gisements de phosphate de chaux du.
Jour. agric. prat., pp. 307-309, 1872.

Morfit (Campbell). Mineral phosphates and pure fertilizers. New York, 1872.

Morton. Cyclopedia of Agriculture. Blackie & Son, London.

Murchison (*Sir* Roderick Impey). On the commercial and agricultural value of certain phosphatic rocks of the Anguilla Isle in the Leeward Islands.
Jour. Roy. Agric. Soc., 1st ser., xx, p. 31.

N.

Naismith (Thomas) and J. F. Potts. Charleston phosphates.
Geol. Mag., viii, p. 235, London, 1871.

Naranjo y Garza (P.) and Lino Peñuelas. Sur la phosphorite de Logrosan (Estrémadure).
Bull. Soc. géol. France, 2e sér., xvii, pp. 157-161, 1860.

Naumann (Carl Friedrich). Staffelite von Limburg.
Elemente der Mineralogie, Leipzig, 1859.

Nesbit (J. C.). On the presence of phosphoric acid in the subordinate members of the Chalk formation.
Quart. Jour. Geol. Soc., London, iv, p. 262, 1848.

——— On the Agricultural Chemistry and the Nature and Properties of Peruvian Guano. London, 1859.

New Hampshire:
HITCHCOCK, C. H. Geol. of New Hampshire, iii, part 5, pp. 94-98, 1878.
JACKSON, C. T. Final Rep. Geol. of New Hampshire, p. 115, 1844.

New Jersey:
BARTLETT, L. American Agriculturist, x, pp. 123, 124, 1851.
COOK, G. H. Ann. Rep. Geol. New Jersey pp. 34-38, 1871.
HUDSON, J. Jour. Roy. Agric. Soc., xii, pp. 249-255, 1851.
JACKSON, C. T. Am. Jour. Sci., 2d ser., xi, pp, 402, 403, 1851.

New York:
EMMONS, E. American Agriculturist, x, pp 81-82, 1851.
HUDSON, J. Jour. Roy. Agric. Soc., xii, pp. 249-255, 1851.

Nichols (James R.). South Carolina phosphates.
Rep. Agric. Soc. Mass., pp. 98-110, 1871-'72.

Nivoit (Edmond). Sur les phosphates de chaux de Ciply, en Belgique.
Compt. rend. Acad. sci., lxxix, pp. 256-259, 1874.

——— Sur les phosphates de chaux du terrain crétacé dans le nord de la France et la Belgique.
Assoc. franç. avanc. sci., 4e session, pp. 662-676, 1875.

——— De l'acide phosphorique dans les terrains de transition et de Lias des Ardennes.
Bull. Soc. géol. France, 3e sér., viii, pp. 357-365, 1879-'80.

North Carolina:
DABNEY. Rep. North Carolina Agric. Experimental Station, pp. 57-83, 1883.
PHILLIPS. North Carolina Phosphates, Wilmington, N. C., 1883.

Norton (John P.). Guanos.
The Cultivator, i, pp. 245-364, 1844.

——— Guano. Elements of Scientific Agriculture. New York, 1860.

Norway:
BRÖGGER and REUSCH. Zeitschr. Deutsch. geol. Gesell., xxvii, pp. 646-702, 1875.
REUSCH and BRÖGGER. Zeitschr. Deutsch. geol. Gesell., xxvii, pp. 646-702, 1875.
SHEPARD. Foreign Phosphates, Charleston, S. C., 1879.
VÖLCKER. Jour. Roy. Agric. Soc., 1st ser., xxi, p. 350, 1860.

P.

Paine (J. Manwaring) and J. Thomas Way. On the phosphoric strata of the Chalk formation.
Jour. Roy. Agric. Soc., 1st ser., ix, pp. 56-84, 1848.

Pennington (Rorke). On the bone caves near Castleton, Derbyshire.
Geol. Mag., pp. 184, 185, London.

Peñuelas (Lino). See Naranjo y Garza (P.) and Lino Peñuelas.

Peron (Alph.). Les gisements de phosphate de chaux de Tarn-et-Garonne.
Bull. Soc. géol. France, 3e sér., ii, pp. 108-120, 1873-'74.

Petermann (A.). Note sur les gisements de phosphates en Belgique.
Bull. Acad. roy. Belg., 2e sér., xxxviii, p. 652, 1874; xxxix, pp. 12, 13, 1875; xlv, p. 3, 1878.

Phillips (W. B.). North Carolina Phosphates. Wilmington, N. C., 1883.

Potts (J. F.). See Naismith (Thomas) and J. F. Potts.

Prestwich (Joseph). On the Crag of Norfolk and associated beds.
Quart. Jour. Geol. Soc. London, xxvi, pp. 281–282, 1870.

——— On the structure of the Crag beds of Suffolk and Norfolk.
Quart. Jour. Geol. Soc. London, xxvii, pp. 115, 116, 1871.

R.

R. (C. E.). The phosphate bed at Folkstone.
Geol. Mag., ii, p. 527, London, 1865.

Reusch (H. H.). See Brögger (W. C.) and H. H. Reusch.

Rey-Lescure (M.). Note sur les phosphatières de Tarn-et-Garonne.
Bull. Soc. géol. France, 3e sér., iii, p. 398–418, 1874–'75.

Richardson (J.). Phosphatic serpulites.
Geol. Surv. Canada, Rep. Prog., 1866–'69, p. 125.

Russia:
SHEPARD. Foreign Phosphates, Charleston, S. C., 1879.
YERMOLOFF. Jour. agri. prat., 1872, i, pp. 660–665.

S.

Seeley (Harry). Notice of Torynocrinus and other new and little known fossils from the Upper Greensand of Hunstanton, commonly called the Hunstanton Red Rock.
Ann. Mag. Nat. Hist., 3d ser., xvii, pp. 173–183, 1866.

——— The rock of the Cambridge Greensand.
Geol. Mag., iii, pp. 302–307, London, 1866.

Shaler (Nathaniel Southgate). Phosphate beds of South Carolina.
Proc. Bost. Soc. Nat. Hist., xiii, p. 222, 1869–'70.

——— Phosphatic limestone, Fayette County.
Geol. Surv. Kentucky, new ser., iv, pp. 18, 65, 1878.

Sharples (Stephen P.). Turk's Island and the guano caves of the Caicos Islands.
Proc. Bost. Soc. Nat. Hist., xxii, pp. 242–253, 1882–'83.

Shepard (Charles Upham, jr.). Foreign phosphates. Charleston, S. C., 1879.

——— South Carolina Phosphates. Charleston, S. C., 1880.

Shepard (Charles Upham, sr.). Guañape Island guano.
Rural Carolinian, May, 1870; April, 1872.

Smith (Eugene A.). Report on the phosphates of Alabama.
Bull. No. 5, Alabama State Dep. Agric., 1884.

Sollas (W. Johnson). Some observations on the Upper Greensand formation of Cambridge.
Quart. Jour. Geol. Soc. London, xxviii, pp. 397–400, 1872.

——— Coprolites of the Upper Greensand.
Geol. Mag., x, p. 92, London, 1873.

——— On the Foraminifera and sponges of the Upper Greensand of Cambridge.
Geol. Mag., x, pp. 268–274, London, 1873.

——— On the coprolites of the Upper Greensand formation, and on flints.
Quart. Jour. Geol. Soc. London, xxix, pp. 76–81, 1873.

——— On the glauconite granules of the Cambridge Greensand.
Geol. Mag., n. s., iii, pp. 539–544, London, 1876.

——— See, also, Jukes-Browne (Alfred J.) and W. Johnson Sollas.

South Carolina:
CÉRIS (A. de). Jour. agric. prat., p. 1327, 1870–'71.
HOLMES. The Great Carolina Marl Bed. Charleston, S. C., 1872.
LEIDY (Joseph). Jour. Acad. Nat. Sci., 2d ser., viii, pp. 209–262, Phila., 1874–1881.
NAISMITH and POTTS. Geol. Mag., viii, p. 235, London, 1871.
NICHOLS. Rep. Agric. Soc. Mass., pp. 98–110, 1871–'72.
POTTS and NAISMITH. Geol. Mag., viii, p. 235, London, 1871.
SHALER. Proc. Bost. Soc. Nat. Hist., xiii, p. 222, 1869–'71.
SHEPARD. South Carolina Phosphates. Charleston, S. C., 1880.

Spain:
BADOUREAU. Bull. Soc. cent. agric. France, xxxviii.
CALDERON. Bull. Soc. géol. France, 3e sér., vii, pp. 11–12, 1878–'79.
DAUBENY and WIDDRINGTON. Jour. Roy. Agric. Soc., 1st ser., v, pp. 406–418, 1845.
——— Quart. Jour. Geol. Soc., i, pp. 52–55, 1845.
EGOZCUE Y MALLADA. Mem. de la Comision del mapa geol. España, pp. 184–300, 1876.

Spain—Continued.

LUNA. Compt. rend. Acad. sci., Paris, lxi, pp. 47-52, 1865.

—— Geol. Mag., p. 446, London, 1865.

—— Compt. rend. Acad. sci., lxiii, pp. 220-221, Paris, 1866.

—— Estudios químicos sobre economía agricola, etc. Madrid, 1868.

MALLADA Y EGOZCUE. Mem. de la Comision del mapa geol. España, pp. 184-300, 1876.

NARANJO Y GARZA and PEÑUELAS. Bull. Soc. géol. France, 2e sér., xvii, pp. 157-161, 1860.

PEÑUELAS and NARANJO Y GARZA. Bull. Soc. géol. France, 2e sér., xvii, pp. 157-161, 1860.

SHEPARD. Foreign Phosphates. Charleston, S. C., 1879.

VERNEY. Jour. Roy. Agric. Soc., 1st ser., vi, pp. 331-333, 1845.

VILANOVA Y PIERA. Compendio de geologia, Madrid, 1872.

VÖLCKER. Jour. Roy. Agric. Soc., 1st ser., xxi, p. 355.

WIDDRINGTON and DAUBENY. Jour. Roy. Agric. Soc., 1st ser., v, pp. 406-418, 1845.

—— Quart. Jour. Geol. Soc., i, pp. 52-55, 1845.

St. John (Spencer). Guano statistics.

Brit. Commercial Reports, lxxii, pp. 525-537, 1878.

Stubbs (William B.). Report on the phosphates of Alabama.

Bull. No. 5, Alabama State Dep. Agric., 1884.

T.

Teschermacher (J. E.). Guano.

American Agriculturist, pp. 23-25; 334-335, 1844.

—— Essay on guano.

Thaer (A. D.). Guano. Principles of agriculture.

Translated by W. Shaw and C. W. Johnson, N. Y., 1846.

U.

Ure (Andrew). Analyses of guano.

Jour. Roy. Agric. Soc., 1st ser., v, pp. 287-306, 1845.

V.

Vennor (Henry G). Phosphate of lime in Canada.

Geol. Surv. Canada, Rep. Prog., 1870-'71, pp. 314-315.

—— Phosphate of lime in Canada.

Geol. Surv. Canada, Rep. Prog., 1871-'72, pp. 123-129.

—— Report on Frontenac, Leeds, and Lanark Counties, Ontario.

Geol. Surv. Canada, Rep. Prog., 1872-'73, pp. 136-179.

Vennor—Continued.

—— Synclinal forms of phosphate rocks in Loughboro' and Bedford Townships.

Geol. Surv. Canada, Rep. Prog., 1873-'74, pp. 107-145.

—— Report of exploration surveys in the rear portions of Frontenac and Lanark Counties, with notes on some of the economic minerals of Canada.

Geol. Surv. Canada, Rep. Prog., 1874-'75, pp. 105-165.

—— Report on surveys in the counties of Renfrew, Pontiac, and Ottawa, with notes on the iron ores, apatite, and plumbago deposits of Ottawa County.

Geol. Surv. Canada, Rep. Prog., 1876-'77, pp. 224-230.

—— Les gisements d'apatite et de plombagine des cantons de Buckingham, Portland, Templeton et Hull, comté d'Ottawa.

Géologique du Canada, pp. 343-363, 1876-'77.

Verney (*Sir* Harry). On the use of Spanish phosphate.

Jour. Roy. Agric. Soc., 1st ser., vi, pp. 331-333, 1845.

Vilanova y Piera (D. Juan). Compendio de geologia. Madrid, 1872.

Villeneuve (H. de). Sur des rognons phosphatés de la craie du département du Nord.

Bull. Soc. géol. France, 2e sér., x, pp. 631-634, 1852-'53.

Völcker (Augustus). On the chemical composition and commercial value of Norwegian apatite, Spanish phosphorite, coprolites, and other phosphatic materials used in England for agricultural purposes.

Jour. Roy. Agric. Soc., 1st ser., xxi, pp. 350-381, 1860.

—— On phosphatic deposits recently discovered in North Wales.

Brit. Assoc. Adv. Sci., p. 37, 1865.

—— On the solubility of phosphatic materials, with special reference to the practical efficacy of the various forms in which bones are used in agriculture.

Jour. Roy. Agric. Soc., 1st ser., iv, No. vii, pt. 1, pp. 179-196, 1868.

Völcker—Continued.

——— Analyses of two samples of Guañape guano.

Jour. Roy. Agric. Soc., 2d ser., vi, No. vii, pt. 1, p. 142, 1870. (In report of consulting chemist for 1869.)

——— On the composition and practical value of several samples of native guano prepared by the A B C sewage process of the Native Guano Company.

Jour. Roy. Agric. Soc., 2d ser., vol. vi, No. xii, pt. 2, pp. 415–424, 1870.

——— Analyses of samples from various cargoes of guano imported from the Ballestas Isles.

Jour. Roy. Agric. Soc., 2d ser., viii, No. xv, pt. 1, p. 229, 1872.

——— Composition of two samples of soluble Peruvian guano.

Jour. Roy. Agric. Soc., 2d ser., ix, No. xvii, pt. 1, p. 261, 1873. (In report of consulting chemist for 1872.)

——— Analyses of Peruvian and other guanos.

Jour. Roy. Agric. Soc., 2d ser., xi, No. xxii, pt. 2, p. 349, 1875. (In annual report of consulting chemist.)

——— On phosphatic guanos. London: W. Clowes & Sons, 1876.

——— On phosphatic guanos.

Roy. Agric. Soc. Report, vii, pt. 2, pp. 440–459, 1876.

——— Analyses of Peruvian and other guanos.

Jour. Roy. Agric. Soc., 2d ser., xiii, No. xxv, pt. 1, p. 189, 1877. (In annual report of consulting chemist.)

——— Analyses of Peruvian and other guanos.

Jour. Roy. Agric. Soc., 2d ser., xiv, No. xxvii, pt. 1, pp. 246–255, 1878; 2d ser., xv, No. xxix, pt. 1, pp. 346–352, 1879; 2d ser., xvi, No. xxxi, pt. 1, pp. 311–321, 1880; 2d ser., xvii, No. xxxiii, pt. 1, pp. 291–299, 1881; 2d ser., xviii, No. xxxv, pt. 1, pp. 333–345, 1882; 2d ser., xix, No. xxxvii, pt. 1, pp. 245–247, 1883. (In annual reports of consulting chemist.)

W.

Wales:

DAVIES. Geol. Mag., iv, pp. 251–253, London, 1867.

——— Geol. Mag., ii, n. s., p. 183, London, 1875.

——— Quart. Jour. Geol. Soc. London, xxxi, pp. 357–367, 1875.

Wales—Continued.

JOHNSON, M. H. Geol. Mag., ii, n. s., p. 238, London, 1875.

SHEPARD, C. U., jr. Foreign Phosphates. Charleston, S. C., 1879.

VÖLCKER. Brit. Assoc. Adv. Sci., p. 37, 1865.

W[alker] (John Francis). The Patton and Wicken phosphatic deposits.

Geol. Mag., iii, n. s., pp. 41–43, London, 1876.

——— On a phosphatic deposit in the Lower Greensand of Bedfordshire.

Ann. Mag. Nat. Hist., 3d ser., xviii, pp. 31–32, 381–386, 1866.

——— A reply to H. G. Seeley's remarks on my account of the phosphatic deposits at Patton, in Bedfordshire.

Ann. Mag. Nat. Hist., 3d ser., xx, pp. 118–121, 1867.

——— On some new coprolite workings in the Fens.

Geol. Mag., iv, pp. 309–310, London, 1867.

——— On a new phosphatic deposit near Upware, Cambridgeshire.

Geol. Mag., v, pp. 26–27, London, 1868.

——— Upware deposits.

Monog. Trigoniæ, No. iii, Palæontographical Soc., xxix, p. 145.

Way (John Thomas). On the composition and money value of the different varieties of guano.

Jour. Roy. Agric. Soc., 1st ser., x, pp. 196–230, 1849.

——— See Paine (J. Manwaring) and J. T. Way.

Widdrington (S. E.). See Daubeny (Charles) and S. E. Widdrington.

Wood (Searles Valentine). On the structure of the Red Crag.

Geol. Mag., iii, p. 371, London, 1866.

Woodward (Samuel P.). Notes on Plicatula Sigillina, an undescribed fossil of the Upper Chalk and Cambridge phosphate-bed.

Geol. Mag., i, pp. 112–114, London, 1864.

Y.

Yermoloff (Alexis). Les phosphates de chaux de la Russie.

Jour. agric. prat., i, pp. 660–665, 1872.

INDEX.

o