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Oil and Gas, Natural Resources, and Energy Journal

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FROM THE DRAKE WELL TO THE SANTA RITA #1: THE HISTORY OF THE U.S. PERMIAN BASIN

A MIRACLE OF TECHNOLOGICAL INNOVATION

JOSEPH R. DANCY*

Abstract

The Permian Basin is the largest petroleum-producing basin in the United States. Located in West Texas and in the southeastern portion of New Mexico, this legendary geologic region has provided a platform from which fortunes have been made and lost. The prolific hydrocarbon bounty of the area results from one of the thickest known deposits of Permian-aged rocks in the world, formed from ancient and biologic-rich seas.

Oil and gas developers originally considered the Permian Basin a "graveyard." The cable tool drilling technology commonly used in the early days of oil and gas exploration did little to change how industry investors perceived the area. This was particularly true before 1922 when this industry-standard technology produced many dry holes and marginal wells. However, this "graveyard" perception changed upon the drilling and subsequent completion of the Santa Rita #1 discovery well in 1923.

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Technology is always a major factor involved with the discovery and identification of viable mineral deposits. But technology's significance did not stop with mineral deposits; it also played an essential role in the discovery, the development, and redevelopment of the Texas Permian Basin. After decades of extensive exploration and development after the 1923 discovery, the collaborative effort of dozens of industry promoters has increased the value of the Permian Basin's resources. This is particularly true over the last decade where the value of the oil and gas properties in this historic basin have increased by hundreds of millions of dollars. This is the result of recent advances in horizontal drilling and hydraulic fracturing technology.

This paper examines the historical origins of oil and gas development leading to the discoveries in the Permian Basin, focusing on those technologies that served as catalysts for development. It also examines how these technologies have evolved over the last century, making the Permian Basin one of the premier energy exploration frontiers on the face of the earth.

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I. Introduction

Technology has always played a dynamic role in the development of North American oil and gas resources.[1] From the earliest wells in West Virginia and Pennsylvania to the latest wells drilled today, modern technological advances improve industry operations by making them more efficient, economic, and environmentally friendly.

This is especially true for the West Texas Permian Basin due to the vast nature of its geology and petroleum resources.[2] Technological advances have taken this 94-year-old oilfield, once considered extensively explored and developed, and transformed it into one of the most economically attractive exploration provinces on Earth.

Permian Basin production rates and reserve values have increased by hundreds of millions of dollars over the last decade due to advances in technology.[3] The history of the Permian Basin is a story of how technology has enhanced the economics of existing hydrocarbon exploration and development, addressing a major global problem (peak oil), for the benefit of society.[4]

II. Permian Basin Geology

The U.S. Permian Basin (the "Permian Basin") is named for the Permian geological age, an era that existed roughly 250 to 300 million years ago.[5] An oil and gas producing Permian Basin also exists in Europe, named after

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1. This is especially true in Texas, as the state is a site for numerous major conventional oil and gas discoveries and the location of four major unconventional shale basins. These basins include the Permian Basin, Eagle Ford Shale, Barnett Shale, and Haynesville Shale.

2. CARL RISTER, OIL! TITAN OF THE SOUTHWEST 284 (1949) (noting that the Permian Basin is a vast area consisting of 88,610 square miles, larger than the State of New York).

3. Some analysts have noted that the value of Permian Basin assets have increased by hundreds of billions of dollars over the last decade, due in part to the massive size of the oilfield and due in part to technology making heretofore uneconomic deposits viable. Interview with Dan Steffens, Chief Executive Officer, Energy Prospectus Group, Houston, Tex., (Dec. 2017).

4. Because of advances in technology, expectations are that efficiencies will continue to lower production costs and improve profitability. As technology has advanced, mineral owners, lessees, the State, and the nation have helped.

5. At the end of the Permian era, the planet experienced its worst mass extinction in history, with 90% of plant and animal life forms disappearing from the face of the earth. *See generally* Peter Brannen, THE ENDS OF THE WORLD: VOLCANIC APOCALYPSES, LETHAL OCEANS, AND OUR QUEST TO UNDERSTAND EARTH'S PAST MASS EXTINCTIONS (2017).

the same geological era.[6] However, this article focuses on the basin located beneath the plains of West Texas.

The Permian Basin consists of two sub-basins. Entirely within the State of Texas, and located on the Permian Basin's eastern edge, is the Midland Sub-Basin. Conversely, on its western edge and partially beneath the lands of New Mexico is the Delaware Sub-Basin. Both the Midland and Delaware Sub-Basins were once ancient seas during the Permian age.[7] And between the ancient Midland and Delaware seas there was once a shallower area of hills or an underwater uplift that separated these two bodies of water. Today the area between the Midland and Delaware Sub-Basins is known as the Central Basin Platform; the area northwest of this area is sometimes known as the Northwestern Shelf.[8]

Both the Midland Basin, the Delaware Basin, and the Central Basin Platform hold substantial oil and gas resources and reserves that are currently being developed using modern technology.[9]

The composition of Permian Basin hydrocarbon deposits is primarily a combination of crude oil and natural gas liquids. In certain areas, however, there are substantial amounts of associated natural gas.[10] Although some geological formations in the Permian Basin contain predominantly natural gas reserves, these areas are in the minority.

In much of the Permian Basin geologists tell us that biomass trapped for hundreds of millions of years effectively created the valuable mineral deposits beneath it. In other words, the pressures, the thermal maturity, and the aging of the hydrocarbons eventually created crude oil and natural gas for future extraction.

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6. Northern Europe is the site of one of the largest natural gas fields in the world, the Permian age Groningen field. The Rotliegend sandstone reservoir rock, with a Zeckstein salt cap rock creating the hydrocarbon trap, located beneath this field produces the natural gas. The source rock for the hydrocarbons is the underlying carbonaceous shales and coal seams. This analysis will focus solely on the North American Permian province.

7. *See Permian Hyperbole*, THE ECONOMIST, http://www.economist.com/news/finance-and-economics/21709532-seductive-myth-making-about-saudi-arabia-texas-permian-hyperbole (last visited Jan. 19, 2018). We will refer to the Midland and Delaware Sub-Basins as the Midland Basin and the Delaware Basin for the purposes of this paper.

8. John A. White, Roth Capital Partners, *The Horizontal San Andres: What a Difference a Year Makes* (July 17, 2017).

9. Geologists indicate that the ancient seas of Permian age extend into Mexico, however that area has not been well explored or developed. In Mexico, the government controls the mineral rights and development, unlike the United States where mineral ownership and capital allocation are typically industry benefits affiliated with private parties.

10. Crude oil also produces a natural gas called "associated gas," which is also known as casinghead gas.

Conventional oil and gas fields exist in those areas of the Permian Basin where reservoir rock has the requisite porosity, permeability, and 'cap rock' in place or faulting to trap any hydrocarbons previously formed. Current estimates rank the Permian Basin as the largest crude oil field in the United States measured both by reserves and production.[11] With the increase in production and drilling activity over the last decade, it now produces roughly 24% of total U.S. production.[12] Much of the increase in production from the Permian Basin has occurred since 2009, following the introduction of several new technological developments that improved the exploration and development process.

The United States Geological Society ("U.S.G.S.") recently evaluated the potential of one formation in the Permian Basin, the Wolfcamp shale, and estimated a potential recovery of 20 billion barrels of oil and 1.6 billion barrels of natural gas liquids.[13] To put this in perspective, the massive East Texas Oilfield—the largest conventional field ever discovered in the lower 48 states—will produce roughly 5.5 billion to 6.0 billion barrels of oil when it is ultimately depleted.[14]

III. The Brine Industry and Pre-Oil Development (1800 – 1859)

The story of oil field technology, and how it developed to make oil and gas developments viable, began long before the drilling of the first oil well in West Texas.

Many of the early oil drilling methods borrowed technologies traditionally used for drilling water well that gradually evolved over hundreds of years.[15] Early North American settlers attempted to locate near

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11. *See* James Osborne, *A Massive Oil Field in West Texas*, DALLAS MORNING NEWS, http://www.dallasnews.com/business/energy/2013/07/25/a-massive-oil-field-in-west-texas-but-how-massive (last visited Jan. 19, 2018).

12. Forty percent of U.S. drilling rig activity occurred in the Permian Basin as of April 21, 2017. *See Permian Basin Oil Production and Resource Assessments Continue to Increase*, U.S. ENERGY INFO. ADMIN., http://www.eia.gov/todayinenergy/detail.php?id=30952 (last visited Jan. 19, 2018).

13. U.S. GEOLOGICAL SURVEY, ASSESSMENT OF UNDISCOVERED CONTINUOUS OIL RESOURCES IN THE WOLFCAMP SHALE IN THE MIDLAND BASIN, NOV. 2016, http://pubs.usgs.gov/fs/2016/3092/fs20163092.pdf. The study also found that 16 trillion cubic feet of associated natural gas is recoverable.

14. JAMES A. CLARK & MICHAL T. HALBOUTY, THE LAST BOOM 257, 286 (1st ed. 1972) (noting that a good sized conventional oil field would be 0.1 billion barrels in size).

15. J.E. BRADLEY, HISTORY OF OIL WELL DRILLING 64-75 (1971) (describing the technical developments of the Ruffner Brothers as they exploited brine wells for profit).

freshwater sources and thousands of water wells were dug by hand.[16] Most of these wells were shallow such that little demand existed for technological advances that would allow early settlers to bore or drill to deeper depths. Experts acknowledge the absence of records that would evidence the drilling or boring of wells in America before the 1800s.[17] As settlers moved to lands away from the Atlantic Ocean, however, they quickly learned that they lacked a basic commodity—salt—that would eventually need deeper wells and more advanced technology.[18] Without refrigeration, electricity, or efficient transport, salt was essential for preserving foods, meats and vegetables either hunted or harvested in season.

Indeed, salt springs existed in many settled areas and, for those residing in coastal communities, even harvested through evaporation of salt water to produce crystalline salt. Yet for those who lived in areas without access to nearby salt springs, a thriving salt business arose to serve their needs, starting in West Virginia. David and Joseph Ruffner, who took over the company from their father, operated one of the first salt foundries.[19] They relied on surface salt springs to supply their evaporation furnaces, and quickly found the demand for crystalline salt exceeded their ability to supply it. To meet demand for their salt, stained red due to the iron oxide contaminants, the brothers drilled for salt water on the banks of the Kanawha River in what is now Charleston, West Virginia.[20] Their efforts formed the first well either drilled or bored, versus dug, in North America.[21]

The Ruffner Brothers began drilling operations in 1806 using primitive spring pole methods with a long iron drill.[22] The brothers could complete the well in a rich brine zone from which they evaporated the water and produced a marketable product.[23] Notably at this time, the brine business

16. *Id*. at 5, 62.

17. *Id.* at 62. Note that this does not mean that landowners did not drill water wells during this era. Every landowner needed a water source, and many dug wells or pits or settled near natural water sources. But few, if any, records document the number of water wells drilled in this time.

18. *Id*. at 5, 62.

19. *Id*. at 63.

20. *Id*. at 64.

21. *Id*.

22. *See id*.

23. The Ruffner well, the Drake well, the Lucas Spindletop well, and the Santa Rita #1 well are, in the author's opinion, probably the four most important wells ever drilled in North America.

was very competitive, and like crude oil in the years that followed prices for the product could vary dramatically. Henry Flagler, one of the founders of Standard Oil with John Rockefeller, entered the salt business in Michigan before he entered the oil business—and promptly went bankrupt when salt prices fell on surging supply and reduced demand after the Civil War.[24]

Many of the brine wells located in the West Virginia area also contained various levels of crude oil. On many occasions participants in the state's growing oil industry would dump pure crude oil into the nearby creeks or rivers to float for miles, creating a greasy shine to the surface.[25] When present with the brine, natural gas could be used as a fuel to evaporate the waters, making the brine foundry more economically efficient.

Illustrating the fact that petroleum deposits, as well as brine water, were well known in the area in 1775, General George Washington had visited the Kanahwa Valley.[26] While there, he acquired an acre of land on the Kanahwa River for public use.[27] The property contained a "burning spring," which was considered one of the great curiosities of the region. It was a hole in the ground up from which issued a jet of gas that burned, when ignited, with a bright flame until extinguished by high winds.[28]

IV. First Permian Basin Wells (1855)

Brine well projects in the Eastern United States were not the only operations to begin using early technological advances. Following the discovery of gold in California in 1849, the U.S. Army Corps of Engineers shouldered the responsibility of drilling a series of fresh water wells across the arid expanse of West Texas and New Mexico to serve local travelers.[29]

The first wells recorded to be drilled in the Permian basin were water wells found near the Pecos River, three or four miles north of the Texas-

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24. EDWARD N. AKIN, FLAGLER: ROCKEFELLER PARTNER AND FLORIDA BARRON 18-19 (Kent State Univ. Press Paperback ed. 1991). Flagler claimed that the salt business gave him a better understanding of pricing and production risks in an unfettered free market, and led him to the partial solution to those risks by controlling transportation and developing an economy of scale to lower costs.

25. BRADLEY, *supra* note 15, at 70. Due to the oil dumped into the river it became known as "Old Greasy."

26. *Id*. at 71.

27. *Id*.

28. *Id*. Later developers looked to petroleum, not brine water, in their promotional ventures.

29. *Id.* at 117.

New Mexico border.[30] The year 1855 dawned the spudding of the first water well that encountered a source of pure and clear water at a remarkable depth of 360 feet.[31] The hope had been that the drillers would find an artesian well, but this formation required pumping from a depth of roughly 290 feet.[32]

Deepening the well to 640 feet to find an artesian source, they encountered another water bearing formation, which also required pumping.[33] Because the driller did not have metal or wooden casing to line the well, they experienced numerous problems with materials falling into the wellbore.[34] A second drilled roughly five miles away experienced similar problems.[35] Nonetheless, the Army Engineers showed that they could drill to a depth of 861 feet and proved they could locate multiple sources of high-quality water.[36] Despite the impressive depth, quite significantly the drillers did not encounter any trace of associated petroleum hydrocarbons according to the official records.[37]

Due to the lack of oil or natural gas shows in these wells, some assumed petroleum was not likely to be present following examination of the data from these wells decades later.[38] The lack of oil shows in the West Texas Permian Basin water wells contrasted with the water wells being drilled in Pennsylvania, West Virginia, and Ohio where many of these wells also had a large amount of oil or natural gas as unwanted byproducts.[39]

These early water wells drilled by the U.S. Army Engineers were the first official wells of any kind drilled or bored in the Permian Basin.[40]

V. The Drake Well (1859): Early U.S. Oil & Gas Development

In 1859, Western Pennsylvania became home to the first well drilled specifically for crude oil extraction in the United States. At the time,

30. *Id.* at 119.
31. *Id*.
32. *Id*.
33. *Id*.
34. *See id.* During these days, casing delivery happened by wagon train, over very desolate terrain, and took months from the date of order and shipment.
35. *See id*. at 119-20.
36. *Id*. at 120.
37. *See id*. at 117-42.
38. *See id*.
39. *See id*. at 70.
40. *See id*. at 117-42.

drilling for either salt water or oil and gas was, as it is now, a capital-intensive business.

Numerous types of business structures had been used to raise capital historically, including the partnership, but at the time the use of the corporation as an organizational form was gaining popularity due to recent state legislative initiatives.[41] The fact that the corporation limited individual liability in what could be a risky venture was also a major attraction of the corporate organizational structure. An example is the formation of the Pennsylvania Rock Oil Company of New York by promoters in 1854 for purposes of developing an oil spring located on lands in Titusville, Pennsylvania.[42]

The promoter initially found it difficult to arouse investor interest in the stock or venture since the uses and value of petroleum had not been well documented.[43] But after studying crude oil collected from natural seeps, a Yale professor employed by the promoters of the venture issued a report in 1855, concluding that petroleum had a multitude of potential uses and could generate significant economic value.[44] This helped increase interest in the venture, and several investors agreed to contribute capital provided the corporate structure was subject to the more liberal Connecticut laws addressing corporate governance.[45]

Incorporated in 1855, the Pennsylvania Rock Oil Company of Connecticut raised $300,000 in capital for exploration and development purposes.[46] With the capital the promoters bought 105 acres of land to develop.[47] The first crude oil produced from the well sold for $19.25 per barrel.[48] A few years later, due to the substantial quantities of oil found in the region, the same oil sold for ten cents per barrel.[49]

But due to a disagreement among the investors interested in developing the property, those wanting to drill formed the Seneca Oil Company of New Haven and subsequently leased the property from the Pennsylvania Rock

41. JOHN MICKLETHWAIT & ADRIAN WOOLDRIDGE, A SHORT HISTORY OF A REVOLUTIONARY IDEA 51-52 (2003).

42. JON SHERMAN, DRAKE WELL MUSEUM AND PARK: PENNSYLVANIA TRAIL OF HISTORY GUIDE 9 (2002).

43. *Id*. at 10.

44. *Id*.

45. *Id*.

46. *Id*.

47. HARTZELL SPENCE, PORTRAIT IN OIL 51 (1st ed. 1962).

48. *Id*. at 52.

49. *Id*. at 51-52 (noting that barrels cost $3 each, such that with oil selling at ten cents a barrel the production was not economic).

Oil Company of Connecticut for immediate development.[50] Employed by the Seneca Oil shareholders to develop the property, Drake bought a small amount of stock in the company.[51]

Drake drilled his well to a depth of 69.5 feet using a six horsepower steam engine.[52] Groundwater flooding and well caving created a problem, so Drake had cast iron pipe rammed into the hole to control such problems.[53] Drake was the first to use casing technology to keep the sides of the well from falling in the hole.[54] Once drilling commenced it proceeded by roughly three feet per day, a slow process.[55] However, through persistence and the use of cable tools—that, at the time, were the standard drilling technology—the "Drake Well" developed.[56]

When completed on August 27, 1859, the shallow well produced roughly twenty barrels of crude oil per day.[57] Although the drilling venture was successful, the cost of the venture exceeded expectations and Drake was more or less broke.[58] Drake drilled a second well that was also a marginal producer but was unable to secure leases in his own name in the prospect.[59] As a result, he sold his rights and interests in the prospect.[60] Poverty and poor health dominated his life after leaving Titusville.[61]

The Drake well was developed under the terms of an oil and gas lease that contained provisions commonly used for the drilling of salt water wells.[62] Salt at the time was used to preserve food. The owner of the land could lease to the driller with the landowner getting a 1/8 royalty on salt production.[63] Later, when oil was the target, the landowner likewise

50. SHERMAN, *supra* note 42, at 10.

51. *Id*.

52. BRADLEY, *supra* note 15, at 117; HAROLD WILLIAMSON, THE AMERICAN PETROLEUM INDUSTRY: 1899-1959 THE AGE OF ENERGY (1963); SHERMAN, *supra* note 42, at 29.

53. *Id.* at 12.

54. *Id*. Drake could have patented the invention but did not do so.

55. *Id*.

56. *Id*.

57. *Id*.

58. *Id*. at 14.

59. *Id*.

60. *Id*.

61. *Id*.

62. American Oil & Gas Historical Society, *Making Hole – Drilling Technology*, AOGHS.ORG, http://aoghs.org/technology/oil-well-drilling-technology/ (last visited Jan. 19, 2018) [hereinafter American Oil & Gas]. Both salt and oil and gas leases have a term clause, royalty clause, description clause, and lease parties.

63. *Id*. In 1802, drillers in West Virginia discovered enough salt water to develop a salt manufacturing center for early settlers.

received a 1/8 royalty on oil production.[64] Therefore, it naturally followed that the same technology and methodology used in salt water well drilling would be utilized when the focus turned to oil.

Technological advancements even played a role regarding the drilling of early oil wells, and regarding the transportation of the products to market. Forty-two gallon wooden barrels crafted nearby stored the produced oil.[65] The industry still uses the barrel as the standard volumetric measure of oil today.[66]

Up to two-thirds the price of oil at the refinery was the cost of delivery, as producers used horse-drawn wagons to carry the barrels from the wellhead.[67] Flat boats travelling down the local creeks to market served as viable alternatives for transporting oil barrels.[68] Oil from the Drake Well eventually, however, incorporated the use of railway cars, significantly increasing the amount of product sent to market from these well locations.[69]

As metallurgy advanced, making transport over intermediate distances feasible, pipelines began to emerge.[70] Pipelines were especially useful when markets were near larger fields. The first pipeline in the Oil Creek area moved 2,000 barrels per day in a five-mile journey from the wellsite, which was a week's worth of work for 300 horse-drawn wagons.[71] Technological advances again led to more efficient and economic operations. Transportation costs and loss in transport, regardless of mode,

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64. EARL A. BROWN, JR., THE LAW OF OIL & GAS LEASES (2d ed. 1973).

65. American Oil & Gas, *supra* note 62.

66. Not all barrel measurements are equal. Although a barrel of beer is customarily 31 gallons, a barrel of oil is actually 42 gallons.

67. SPENCE, *supra* note 47, at 209.

68. SHERMAN, *supra* note 42, at 16.

69. American Oil & Gas, *supra* note 62. James and Amos Densmore of Meadville, Pennsylvania, received the patent for their "Improved Car for Transporting Petroleum" in 1866.

70. In another display of technical innovation, Samuel Van Syckel constructed a five-mile two-inch cast iron pipeline from the Drake well area, the first oil pipeline ever constructed, which substantially reduced the cost of transport charged by the teamsters. *See* Samuel T. Pees, *1865, The Van Syckel Pipeline*, PETROLEUMHISTORY.ORG, http://www.petroleumhistory.org/OilHistory/pages/Pipelines/van_syckel.html (last visited Jan. 19, 2018).

71. SPENCE, *supra* note 47, at 209. While the pipeline charged $1 per barrel versus the $3 per barrel charged by the teamsters, the trip from Oil Creek to New Jersey was another $8 using non-pipeline facilities.

typically absorbed a significant portion of the sales revenue for the product.[72]

VI. New Production and Markets (1880 – 1900)

Exploration and production expanded after the 1859 Drake Well discovery, moving from Pennsylvania into West Virginia and Ohio, and eventually Indiana and Illinois. As of 1900 these states were the primary oil producing provinces in the United States. John D. Rockefeller, during this time, was able to monopolize much of the transportation, and refining capacity in these areas under the Standard Oil umbrella, which allowed him to build a fortune in this new industry.[73]

As new markets for crude oil developed, including the demand generated by the internal combustion engine, the public grew concerned that oil supplies would not be sufficient to meet the long-term demand growth.[74]

In the emerging automobile industry, batteries powered roughly one-third of vehicles, steam powered one-third, and internal combustion engines powered one-third by 1900.[75] At that time the internal combustion engine was comparatively noisy, dirty, vibrated violently and was difficult to start. However, many of these drawbacks were eventually overcome as the automotive engine technology advanced.

VII. Spindletop (1901): The Age of Oil

An event that occurred in Southeast Texas in January of 1901 changed the future of energy use forever and ultimately solved the growing concern around crude oil's scarcity. Using technological advancements deployed

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72. Even today many systems track "lost or unaccounted for" gas or oil, referred to as system "lug." High lug levels indicate problems with measurement, engineering design, or pipeline integrity, and reduce economic returns. *Id*.

73. Henry Flagler, partner with Rockefeller, was instrumental in arranging transportation modes for the crude oil in a way that would benefit the Standard Oil companies. Oil, without a reasonably priced transportation method to reach the end use market, is of little value at the wellhead. AKIN, *supra* note 24, at 24.

74. *Id.*

75. *The History of the Electric Car*, U.S. DEP'T OF ENERGY, http://energy.gov/articles/history-electric-car (last visited Jan. 19, 2018) (noting that electric cars had roughly one third market share in 1900, and shared the market with steam and internal combustion vehicles).

after the failure of two prior drilling attempts, a well on Spindletop Hill blew out at a location near Beaumont, Texas.[76]

The first technological advance that allowed the Spindletop developers to make the discovery was the fact the drillers utilized a rotary rig versus cable tool drilling technology.[77] As the well deepens, the pipe of a rotary rig rotates, versus the up-and-down pounding of a drill bit used in cable tool drilling. The rotary rig proved more effective in drilling though the loose sands encountered at the Spindletop wellsite.

The developers inserted "mud" from a nearby pond pumped through the drill pipe into the wellbore to hold back loose sand from falling into the well.[78] The loose, quicksand-like condition heretofore clogged the wellbore of the first two cable tool drilled wells.[79] This made drilling deeper and completing the wells impossible.[80] These technological advances would be used in future years to control downhole well pressures and enhance drilling productivity.

Productive sand was encountered on January 10, 1901, and an estimated 100,000 barrels per day of crude oil blew skyward from the Spindletop wellbore.[81] For the first time in world history, and probably the last, production from one well doubled global oil productive capacity overnight.[82]

The geology of the Spindletop well was unique compared to that of existing fields in Ohio and Pennsylvania. Located in southeast Texas near the Louisiana state line, because drilling for Spindletop commenced into an oil field that was already associated with the apex of an underground salt dome.[83] Historically, Ohio, West Virginia, and Pennsylvania oil reservoirs

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76. Originally named "Sour Creek Hill," the 25-foot-high hill claimed to emit a sulfurous odor from the substances trapped beneath according to locals. JO STILES ET AL., GIANT UNDER THE HILL, A HISTORY OF THE SPINDLETOP OIL DISCOVERY AT BEAUMONT, TEXAS, IN 1901, 106-09 (2002).

77. WILLIAMSON, *supra* note 52, at 29.

78. STILES ET AL., *supra* note 76, at 99.

79. *Id*. at 47-48, 50, 52 (noting the first well was drilled by a rotary rig into sand and was damaged at 415 feet and that two cable rig attempts failed due to sand intrusion).

80. *Id.* at 48 (notes leaving sand in the well).

81. *Id*. at 116.

82. William J. Knights, Vice President, Netherland & Sewell Oil and Gas Property Evaluation Seminar (2015).

83. Salt dome formations are relatively common along the Gulf of Mexico coast as well as offshore. Either above the dome or along the side is where the salt formation tends to trap oil or natural gas. *See* HOUSTON FAUST MOUNT II, OIL FIELD REVOLUTIONARY: THE CAREER OF EVERETTE LEE DEGOLYER 100-02 (2014). Due to the physical nature of the salt, these

generally involved oil or gas structural traps in areas once covered by ancient seas—no salt domes existed.

VIII. West Texas Oil Fields (1900 – 1922): The Permian Basin

For the time period, from 1900 to 1922, potential oil and gas production in West Texas was a remote thought.

Due to the sparse population, arid nature of the land, lack of skilled labor, and lack of transportation facilities, explorationists generally avoided West Texas. Few developers would risk investing funds for leases or by drilling in West Texas. Wildcat drillers even considered West Texas a "graveyard."[84]

When the State of Texas joined the United States, it dedicated millions of acres of western ranch land to support higher education.[85] For years, Texas leased its land for grazing purposes, but the arid nature of the land and remote location led to a situation where agricultural rentals were modest.[86]

Mineral leasing for oil and gas exploration and drilling activity in West Texas, at least in the Permian Basin area, was rare in the early 1900s. A University of Texas geology professor, Dr. Johan Udden, conducted a study of the Permian Basin lands in 1916 and concluded that in his opinion the lands could in fact hold substantial quantities of oil and gas even though none had been found to date.[87]

The problem for developers was that oil prospectors at the time considered the West Texas area a haven for dry holes. The credibility of

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domes could be located using the torsion balance to measure changes in gravitational fields. The oil would accumulate at the top of the dome, and was often trapped along the side of the salt intrusion.

84. SAM MALLISON, THE GREAT WILDCATTER: THE STORY OF MIKE BENEDUM 327 (1953); *see also* GUS CLEMENS, LEGACY: THE STORY OF THE PERMIAN BASIN REGION OF WEST TEXAS AND SOUTHEAST NEW MEXICO 133-39 (1983).

85. In 1876, the Texas Constitution allocated acreage to endow the Permanent University Fund. These lands were leased for surface grazing, agricultural use, and for oil and gas drilling. MALLISON, *supra* note 84, at 326.

86. Geologist L.C. Snider stated the Permian rocks "have not yielded any oil or gas . . . and their nature is such that it seems improbable that any will be found in them." MIKE COX, TEXAS PETROLEUM, THE UNCONVENTIONAL HISTORY 41 (1st ed. 2015) (internal quotations omitted).

87. CLEMENS, *supra* note 84, at 133-39. Dr. Udden when describing the geological structure noted "it does not appear unreasonable to regard it as suggesting the possibility of the presence of buried structures in which oil may have accumulated." COX, *supra* note 86, at 41 (internal quotations omitted).

geologists, even geology professors, became subject to scrutiny due to the new nature of their science and expertise.[88]

As of the 1920s no producing oil field had been discovered within 100 miles of the Permian Basin.[89] Adding in the remote nature of the lands, lack of manpower, the physical difficulty getting equipment to the area, led to a situation where few were willing to take a chance drilling.

Those that *did* explore the Permian Basin prior to 1923 generally encountered a series of dry holes or very marginal wells.[90] Several wells were drilled in the 1880s that were dry, although a small oil field was discovered in Reeves County in 1903.[91] A well drilled in 1920 on the Eastern Shelf of the Midland Basin produced somewhere between 10 and 50 barrels of oil per day.[92]

Rupert Ricker, a University of Texas law student at the time from a small town in the Permian Basin, heard about Dr. Udden's geological study of the Permian Basin lands.[93] When he graduated, Ricker decided to try to raise money to explore the Permian Basin, leasing lands for oil and gas from the State in 1920.[94]

Under the State of Texas leasing rules in place at the time, Ricker acquired rights to roughly 431,360 acres (680 square miles).[95] Under the lease terms, Ricker had 30 days in which to pay the oil and gas rental payments.[96] The rental payments amounted to $43,136, ten cents per acre, as provided for in the statute.[97] Attempting to raise the money from investors to pay for the leasehold rights, he was unable to generate sufficient interest or funds.[98]

To recover at least a some of the costs he incurred in the leasing process, Ricker sold the right to acquire the leases to a promoter named Frank

88. BOBBY WEAVER, OILFIELD TRASH: LIFE AND LABOR IN THE OIL PATCH 109 (2010).

89. MIKE COX, WEST TEXAS TALES 100 (2011).

90. *See* CLEMENS, *supra* note 84, at 133-39.

91. *Id*.

92. The Abrams #1 well was drilled in Mitchell County and produced roughly 10 to 100 barrels of oil per day. The well was located on the Eastern Shelf, or edge, of the Permian Basin. COX, *supra* note 86, at 41-49. The literature is inconsistent as to how productive the well actually was, possibly because the well was torpedoed with nitroglycerin, which would impact short term production rates.

93. CLEMENS, *supra* note 84, at 133.

94. *Id*.

95. *See* COX, *supra* note 86, at 41-49; *see also* MALLISON, *supra* note 84, at 328.

96. CLEMENS, *supra* note 84, at 133.

97. *Id*.

98. *Id*. at 134.

Pickrell for $2,500.[99] Pickrell agreed to pay the initial lease rentals if he could raise the funds.[100] Ultimately Ricker's applications for the leases expired and Pickrell had to re-file applications with the State of Texas for the leases.[101] Pickrell organized a company he named Texon Oil & Land Company to raise capital and to develop these leases; he planned to drill an exploratory well within 18 months somewhere on the property.[102]

IX. Cable Tool Drilling Technology

In the early years oil and gas wells were drilled using cable tool rigs.[103] Early Permian Basin development also saw the use of cable tool rigs almost exclusively, although rotary rigs had been introduced and were becoming more popular since they generally were much more efficient.

Utilized for hundreds of years to drill water wells, the oil and gas industry adopted this methodology as those products became valuable. Landowners drilling for water frequently encountered natural gas or crude oil in Pennsylvania, New York, and Ohio according to early reports.[104] In the early 1800s, salt springs created a robust and profitable salt manufacturing industry in West Virginia as the brine was evaporated.[105] Too much natural gas or crude oil would ruin a good water well, to say nothing about creating safety issues.[106]

Much of the technology and methodology used in early oil well drilling evolved from the drilling of salt water wells.[107] The first well drilled in North America, as opposed to dug, was a salt water well drilled by the Ruffner brothers in West Virginia in the early 1800s.[108] It was common for natural gas to also be discovered in salt water wells, as it practical uses extended into the manufacturing process to evaporate the water.

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99. *Id*.

100. *See id*. at 133-35.

101. *Id*. at 134.

102. *Id*. at 134-35 (indicating that the Texas legislature amended applicable statutes, allowing larger blocks of acreage to be leased, and extended the term of the leases issued by the State by six months); *see also* COX, *supra* note 86, at 41-49.

103. WILLIAMSON, *supra* note 52, at 29.

104. BRADLEY, *supra* note 15, at 153-54.

105. *Id*. at 62, 71.

106. *See* American Oil & Gas, *supra* note 62. The Ruffner brothers drilled for salt water in 1802 in West Virginia and established a manufacturing and distribution center for salt. Any associated oil was sold as a medicine.

107. *See* BRADLEY, *supra* note 15, at 62-71.

108. *Id*.

Cable tools make holes by slowly pounding the rock with a drill bit.[109] Cable tool technology provided the driller few options to control downhole pressures that might be encountered in oil and gas formations. As a result, many early cable tool wells "blew in," which resulted in a great waste of oil and gas, substantial damage to the environment, and created a substantial fire hazard.[110]

In addition to the problems noted above, when a well erupted the public quickly became aware of the potential value of the surrounding leases. Third parties could take financial advantage of the event by leasing lands near the productive well, even though the driller and developers had incurred all the drilling and economic risks.

In most cases the power source for the cable tool rig was the steam engine. In areas of West Virginia, Pennsylvania, Ohio, and Indiana, the water and fuel for the steam engine was abundant, usually wood from the local forest or coal.

When cable tool rigs moved to arid areas such as West Texas, Western Oklahoma, and Western Kansas, not only was fuel in short supply, but many times water was not readily available in the quantities needed to generate steam. It was not uncommon to ship water and fuel to the drill site to supply the steam engine.

Due to the nature of the cable tool drilling, the vertical lifting and dropping of a heavy weight with a pointed tip to break the rock, wells drilled using this method could only be drilled vertically or nearly so. It was difficult, if not impossible, to deviate a hole from vertical.

Every three feet or so, the rock clippings or chips had to be removed from the well bore to allow drilling to proceed. In extremely sandy formations, like that encountered in Southeast Texas, the location of the Spindletop well, sand would cascade from the wellbore walls into the well, making cable tool drilling difficult or impossible.[111]

Because of the nature of the drill bit, the drilling method, and the cleaning out of the well, the cable tool drilling operations were generally slow. When drilling for water, many of those wells were less than 100 feet

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109. *See* Hughes Tool Co. v. Ford, 114 F. Supp. 525 (E.D. Okla. 1953).

110. Some reports were that early Pennsylvania settlers when drilling a water well had them ignite due to the natural gas, throwing "fire and brimstone" on the landscape. Some claimed that the driller had drilled all the way to hell. Natural gas seeps that ignited were referred to as burning springs. *See* American Oil & Gas, *supra* note 62.

111. *See id.* The drillers utilized a rotary rig when drilling the Spindletop well because earlier attempts using cable tool rigs failed due to sand intrusion into the wellbore.

deep, so the cable tool process was acceptable from an economic and technological standpoint.

The cable tool drilling method had several advantages for the developer. First, the driller could continually monitor the lithology of the well during the drilling. Second, any oil or gas shows would be quickly noted. It became relatively easy for the developer to identify exactly from what depth and strata the oil or gas production originated.[112]

An operator in the 1930s commonly drilled a well to the top of the target zone using a rotary rig, then complete the well using cable tool technology.[113] Due to these advantages, and several drawbacks of the more advanced rotary rigs introduced around 1900 in certain fields, cable tool rigs were utilized for a much longer period in the Permian Basin than elsewhere.[114]

X. Santa Rita #1 (1923) Permian Basin Discovery Well

Frank Pickrell, like law student Ricker, had difficulty raising funds from potential investors to explore the Permian Basin. Pickrell had formed the Texon Oil & Land Company to raise capital for the venture.[115] Hugh Tucker, a geologist Pickrell had hired at Texon, pinpointed a location on the Permian Basin leases at which to locate a well.[116]

Transportation options at that time were such that moving a cable rig to the specific location identified by geologist Tucker would be extremely costly and time-consuming. Nonetheless, the promoter contracted for a cable tool drilling rig and had the rig transported to a location around 14 miles west of Big Lake, Texas, on the railroad line running through the area.[117]

Time constraints and lack of capital required setting the cable tool rig 124 feet north of the railroad right-of-way, miles away from the location

112. WILLIAMSON, *supra* note 52, at 29-32. In rotary drilling the drilling mud might mask productive zones, keeping the hydrocarbons trapped in formation.

113. *See, e.g.*, Hall v. Warren Bradshaw Drilling Co., 40 F. Supp. 272 (N.D. Tex. 1941); Corbett v. Schlumberger Well Surveying Corp., 43 F. Supp. 605 (S.D. Tex. 1942).

114. WILLIAMSON, *supra* note 52, at 29. Cable tools were also used longer in West Virginia and the Rocky Mountain area, but were quickly replaced by rotary rig technology in those areas with sand or shale formations that inhibited cable tool drilling due to wellbore instability.

115. MALLISON, *supra* note 84, at 333.

116. CLEMENS, *supra* note 84, at 35-36. A well later drilled at the location identified by geologist Tucker ironically was dry.

117. WEAVER, *supra* note 88, at 108.

geologist Hugh Tucker had selected for the well.[118] Pickrell also found that he needed to spud the well almost immediately to extend the term of the lease, and further that he had neither the funds or the time to transport the equipment to the desired location.[119]

The wildcat well was christened the Santa Rita #1 well. Pickrell had a part of the required drilling funds but needed more, so visited New York City where he obtained funds from interested third-party investors.[120] The well was named after Santa Rita the Catholic Saint of the Impossible.[121]

Drilling using cable tools is extremely slow in the best of times. In the Permian Basin area there was a lack of water and a lack of fuel for the steam engine that powered the drilling apparatus. Timely spudded, however, the Santa Rita #1 well preserved the leases.[122] Drilling was extremely slow due in part to material shortages, labor shortages, and the nature of the geology. The well took 20 to 21 months to drill to a depth of just over 3,000 feet.[123]

Because cable tool drilling methodology does not provide the means to address high-pressure natural gas or oil, on discovery these substances generally rushed from the formation into the wellbore. The oil and gas frequently moved upward in the wellbore with extreme force, resulting in an uncontrolled well condition. Many times, the highly-pressurized oil or gas would damage the cable tools or rig during the eruption as the well "blew in," and it was not usual for a crater to form around the wellbore.

May 27, 1923 marked completion of drilling activity on Santa Rita #1, and the well sat quietly overnight. Before the day's operations could commence, the well began to blow out the morning of May 28.[124] The well erupted every twelve hours for a number of days, alerting the public that there could be substantial amounts of oil wealth hidden underground.[125]

The Santa Rita #1 well produced roughly 100 to 150 barrels per day of oil, along with substantial water, during the eruptions.[126] While a fraction

118. *Id*. (indicating the well was 174 feet north of the railroad); MALLISON, *supra* note 84, at 323 (indicating that the well was 150 feet north of the tracks).

119. *Id*.

120. *Id*. at 110.

121. *Id*.

122. *Id.* at 108.

123. *See* CLEMENS, *supra* note 84, at 134-36.

124. WEAVER, *supra* note 88, at 110.

125. *Id*. (indicating also that a train of spectators was brought to the wellsite in early June, with an estimated 1,000 visitors observing the periodic blowouts).

126. *See* MALLISON, *supra* note 84, at 331.

of that from the East Texas Spindletop well, it was nonetheless the first discovery that would lead to substantial oil production in the West Texas Permian Basin.[127]

As with Spindletop, the rural, sparsely-populated arid area created challenges with regard to transportation of the product to market. In many areas of the Permian Basin at the time, water was more valuable than oil, and the cost of moving oil from the remote area to market was prohibitive.[128] Fortunately, the drill-site had at least one advantage: Because drilling for the Santa Rita #1 commenced near a railroad, upon completion, producers could later use rail cars to transport oil to market—the nearest pipeline was some 125 miles away.[129] The developers built seventeen oil storage tanks nearby, each with a capacity of 80,000 barrels, and eventually a 400-mile pipeline to the refineries on the Texas coast.[130]

XI. Permian Basin Santa Rita & Related Development Wells

Under the terms of the State of Texas oil and gas leases acquired by Frank Pickrell, numerous wells were required to be drilled to extend the terms of the leasehold acreage. Pickrell had commenced drilling two additional development wells after the Santa Rita #1 but found they could not raise sufficient capital and quickly ran into financial difficulty.[131]

To address the problem, he negotiated the sale of a large portion of the leasehold interest, as well as the interest in the Santa Maria #1 discovery well.[132] The interest was purchased by two well-known and successful wildcatters from Pittsburgh, Michael Benedum and Joseph Trees.[133] Benedum initially did not proceed to acquire an interest in the new well and field due to pre-existing financial commitments elsewhere, but when

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127. Some claim that the 1920 Abrams #1 was the first commercial well completed in the Permian Basin. The accounts differ as to how productive that well was from an economic standpoint.

128. Drinking water was shipped to the wellsite from Big Lake, a dozen miles to the east. CLEMENS, *supra* note 84, at 143; MALLISON, *supra* note 84, at 344-45.

129. COX, *supra* 89 at 100.

130. WEAVER, *supra* note 88, at 111.

131. *See* Henderson v. Plymouth Oil Co., 13 F.2d 932 (W.D. Pa. 1926).

132. Pickrell sold a 75% undivided interest in the leases on the condition of future drilling of several new wells by purchasers. *See* CLEMENS, *supra* note 84, at 137.

133. Benedum had originally told Pickrell he had no interest in the Permian Basin leases and recommended he talk with the majors about development. Pickrell returned to Benedum and Trees several months later after the majors showed no interest, and they were impressed that the production from the initial well had held up so well. MALLISON, *supra* note 84, at 322; *see also* CLEMENS, *supra* note 84, at 137.

Pickrell returned several months later and the well was still producing, Benedum decided to take another look.[134]

On further geological evaluation, Benedum decided to acquire an interest in the leases and to commit himself to developing the property by the drilling of several more wells.[135] Benedum and Trees formed the Big Lake Oil Company to develop the property and paid around $450,000 for the assets and agreed to bear development costs.[136] These parties agreed to drill at least eight wells on leases surrounding the Santa Rita #1 discovery well.[137] In addition, Benedum and Trees also formed a parent company to hold Big Lake Oil Company stock, Plymouth Company, that they used to raise capital and to invest in West Texas ventures other than the Santa Rita leases.[138]

The first eight wells drilled by Benedum and Trees after the Santa Maria #1 discovery well were marginal at best.[139] Despite this fact, the wildcatters decided to allocate more capital and to continue drilling on the prospect.[140] While wells number two through eight were marginal, the Santa Maria #9 and the Santa Maria #11 wells observed initial flows of anywhere from 3,000 to 8,000 barrels per day.[141] These flow rates, if maintained, would make the prospect economic.

Benedum and Trees drilled the first wells using steam engines and cable tools, with very basic equipment.[142] Although they used a rotary rig to drill well #10, the operation apparently did not prove cost effective, as the operator went back to cable tool operations for subsequent wells.[143] To address the need for stable oilfield labor, Benedum and Trees built the town of Texon (named after Pickrell's company) to house oilfield labor and provide some of the comforts of city living.[144]

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134. MALLISON, *supra* note 84, at 331-34.

135. *See Plymouth Oil Co.*, 13 F.2d at 932; Henderson v. Plymouth Oil Co., 19 F.2d 97 (3rd Cir. 1927).

136. *See Plymouth Oil Co.*, 13 F.2d at 933-34.

137. The agreement into which Benedum and Trees entered conditioned the drilling of these wells only if the cost was less than $50,000 each. MALLISON, *supra* note 84, at 333.

138. *See* COX, *supra* note 86, at 41-49; *see also* MALLISON, *supra* note 84, at 334; *Plymouth Oil Co.*, 13 F.2d at 932.

139. MALLISON, *supra* note 84, at 340.

140. *Id*. at 342.

141. *Id*.

142. *Id*.

143. *Id*.

144. *Id*. at 346.

With the amount of production being discovered, it was apparent the storage facilities and transport via railroad would be insufficient to handle the substantial volumes being produced. E.W. Marland and the Marland Oil Company formed the Reagan County Crude Purchasing Company to purchase and transport the production from Texon Oil & Land Company and Big Lake Oil Company with the goal of building a pipeline from the field to Texas City on the Gulf Coast.[145]

Marland figured the pipeline would cost five million dollars and that it would save three million per year in freight charges.[146] Unfortunately, the Executive Committee of the Marland Oil Company Board of Directors would not let him proceed with the project, perhaps due to the fact that certain financial interests represented on Marland's Board expressed strategic concerns about offering the volume of oil into the global marketplace.[147]

After the development in the Santa Rita #1 area, Benedum had acquired more leasehold to develop, including leases on the Yates Ranch.[148] To raise capital, he approached the Ohio Oil Company, which agreed to drill four exploration wells in return for a leasehold interest.[149] Ohio Oil drilled three dry holes and was considering its option to terminate the contract, but their geologist argued for one final exploration well.[150]

In 1926, Ohio Oil offered to buy out Benedum, assuming he might not want to continue after three dry holes, but he refused and participated in the last test well on the Yates Ranch.[151] The Yates well struck oil at 997 feet, a very shallow well, but had an impressive flow of 3,240 barrels per hour.[152]

By the time they drilled the Yates #30-A well a year or so later, the initial production rate observed by the developer was 204,600 barrels per

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145. JOHN MATHEWS, LIFE & DEATH OF AN OILMAN: THE CAREER OF E.W. MARLAND 173 (1951).

146. *Id*. at 173-75.

147. MATHEWS, *supra* note 145, at 173-76.

148. SPENCE, *supra* note 47, at 120.

149. *Id*. at 121. The contract also provided that the Ohio Oil Company could cancel their drilling commitment with a small cash payment.

150. *Id*. at 121-22.

151. *Id*. at 126 (77,760 barrels per day).

152. MALLISON, *supra* note 84, at 309. The oil zone was encountered much shallower than expected which allowed for subsequent wells to be drilled by a mobile cable tool drilling rig. The well was productive from the Big Lime formation, today known as the San Andres formation, a formation that is still productively encountered in new wells. SPENCE, *supra* note 47, at 124-27.

day, a record for both the State of Texas and the world.[153] These wells illustrated the potential viability of the Permian Basin and were the largest discoveries ever for successful wildcatters Benedum and Trees.[154]

XII. The Nitroglycerin Torpedo

Crude oil in the ground is frequently trapped in formations at high pressure and at elevated temperatures. Once liberated from that high pressure, high temperature environment, dissolved substances in the oil or gas are likely to precipitate as the oil cools and reaches ambient pressure.

One of the early operational issues that many crude oil producers experienced was the fact that oil wells would tend to plug up with paraffin, wax, tar, or similar substances.[155] The quality of the oil determined how much wax or paraffin precipitated out of the oil.

In addition to impurities, formations that developers encountered may have lacked the required permeability to allow the oil or natural gas to migrate from the formation into the wellbore.

A creative inventor named Edward Roberts designed a solution to the problem: an explosive charge he would insert in the wellbore.[156] The blast would clean the well bore of wax and paraffin. If the blast was powerful enough, it also had the benefit of creating additional fractures in the rock, which increased permeability, allowing the oil to flow more freely to the wellbore.

Before shooting the well, a metal canister containing an explosive (usually nitroglycerin) would be placed in the well and then lowered to the

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153. The wells were so prolific that the developer had to install storage and the site and later a pipeline was built to move the oil to market. Mike Benedum and Joseph Trees, like the Santa Rita field, developed the Yates field. MALLISON, *supra* note 84, at 311.

154. In the end, the industry later recognized the collective effort of Benedum and Trees as the earliest developers of one of the richest oilfields in American history—the Permian Basin. MALLISON, *supra* note 84, at 321. In 1990, after sixty-seven years of service, the Santa Rita #1 received its plug—ending its production for good. Bailey Leroux, *The Well that Launched the Permian*, PERMIAN BASIN PETROLEUM ASS'N MAG., http://pboilandgasmagazine.com/the-well-that-launched-the-permian/ (last visited Jan. 20, 2018).

155. WILLIAMSON, *supra* note 52, at 152. The oil industry eventually adopted the practice of placing of an explosive charge at the bottom of a water well to enhance the well capacity, receiving similar positive results increasing well productive capacity.

156. *Id*. at 148. Early water well drillers inserted charges into the wells to enhance flow rates, from which Roberts apparently borrowed the idea. Initially Roberts used black powder, then advanced to nitroglycerin, which was much more powerful but also much more dangerous. Unexpected or premature explosions caused the injury or death of many people.

point where the blast was desired. A pointed rod was then dropped into the well, and when penetrated, the canister exploded. Usually the operator filled the well with water to help keep the explosive pressures directed into the wellbore walls. This water also had a great effect at the surface as it was shot out of the well on ignition.

Roberts patented the process and charged $100 to $200 per shot, with an additional royalty of 1/15 of any increased production from the blast.[157] This is in the late 1800s, so these charges were quite substantial.

As a result of the substantial cost of shooting using the Roberts torpedo, a number of producers rigged their own explosives to shoot wells. This violated the patent which resulted in a large amount of litigation.[158] Since the blasts were illegal, these producers generally shot at night, hence creating the term "moonlighter."[159]

Nitroglycerin is very unstable. Getting the substance to the well site was a challenge since many of the roads were dirt and mud, full of rocks and holes. It was common for the explosive to detonate during transportation or prematurely at the well, causing many deaths and injuries.[160] Nonetheless, torpedoing a well usually resulted in increased production—and eventually was replaced with hydraulic fracturing techniques utilized today.

XIII. Rule of Capture & the Permian Basin

Every major oil producing country in the world considers the oil and gas underlying the land to be part of the national heritage and public property to be developed under concessions obtained by private developers.[161] In general the operator leases large tracts of land from the government, sometimes the entire field, where development can proceed at a reasoned pace and in a logical manner.

In the United States, by contrast, sub-surface wealth generally belongs to the owner of the land, not the government.[162] Many of these tracts are smaller plots, on which development proves problematic. To complicate matters further, early courts adopted an ownership theory about oil and

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157. *Id*. at 152. An estimated cost to manufacture the torpedo was $20, so the margins were incredibly lucrative. Enforcing his patent, Mr. Roberts became responsible for more litigation than any U.S. citizen.

158. *Id*.

159. *Id*. at 154.

160. The Abrams #1 well, drilled on the Eastern Shelf of the Midland Basin, was shot with nitroglycerin in 1920. *Id*.

161. SPENCE, *supra* note 47, at 180.

162. *Id*. at 181.

natural gas referred to as the "Rule of Capture."[163] The rule stated that oil or natural gas is not owned until either captured or produced.[164] Following the development of wells like those drilled on Spindletop in 1901, and other discoveries of similar significance, developers attempted to drill and produce as quickly as possible, regardless of market conditions.

Due to the lack of transportation facilities and remote location of many of the new discoveries, much oil and natural gas was wasted or lost. Within two or three years of discovery, the major producing sand at Spindletop well had been mostly depleted of its reservoir pressure.

After the 1901 Spindletop discovery, wildcatters began focusing northward and discovered the impressive Glenpool (1905) and Cushing (1912) fields in Oklahoma, some of the early discoveries occurring even before statehood (1907).[165] In these fields there was a rush to develop and produce, again due in large part to the ownership rules established under the Rule of Capture.

The Santa Rita #1 and accompanying Permian Basin wells were somewhat unique in that they were drilled on a very large oil and gas lease block. Oil or natural gas was extremely unlikely to migrate far across lease lines in this area due to the distances, so the developers did not have to engage in a "drilling" or "production" race to establish ownership of the oil.

Likewise, later development was generally conducted on larger leases, removing a major concern that a competitor may drill nearby, drain the oil, and establish ownership of the oil or gas for themselves.[166]

Because of this situation, the reservoirs in the Permian Basin have in general been developed more effectively with less waste, and more of the oil or natural gas in place has been recovered than in other fields.

XIV. Rotary Rig Drilling Technology

As wells were drilled to deeper formations, rotary drilling turned or rotated the drill pipe in the hole (versus pounding a drill bit up and down as was the case with cable tool rigs). The rotary rig technology replaced cable tool drilling and began to be adopted around 1900 and thereafter.[167] Rotary

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163. *Id.*

164. *See generally* Kelly v. Ohio Oil Co., 49 N.E. 399 (Ohio Sup. Ct. 1897).

165. *See generally* KENNY A. FRANKS, THE RUSH BEGINS: A HISTORY OF THE RED FORK, CLEVELAND AND GLENN POOL OIL FIELDS (1984).

166. The "Rule of Capture" states that oil and gas is not owned until it is captured, so any competitor drilling near a lease line may drain oil and ownership from under one's land.

167. BRADLEY, *supra* note 15, at 257; WILLIAMSON, *supra* note 52, at 29.

rig drilling technology for oil was adopted from the drilling of shallow water wells where rotary rigs could drill wells both quickly and economically.[168]

The rotary rig drilling process has certain technological advantages over cable tool rigs. First, the rotary drilling technology injected water or drilling mud through the drill pipe that helped control any high-pressure oil and gas zones that might be encountered. While not actually "drilling mud," in the early years, soft shales and clays dissolved by the injected water created an effective mud in many early wells drilled near Corsicana, Texas, in the 1890s.[169]

Second, drill cuttings were continually removed from the well bore to the surface that made the drilling process more efficient.[170] The water or mud also cooled and lubricated the drill bit. Third, the mud would help stabilize the well to prevent the sides from falling into the hole.[171]

The rotary rig also has the advantage of allowing the driller to deviate the well from the vertical. With rotary drilling, the drill-bit constantly turns to the right as it penetrates the ground. As a result, in many cases it makes a corkscrew-like wellbore as drilling continues.

Such deviation could be used to cross lease lines, effectively draining oil from under neighboring lands. In some parts of the East Texas Oilfield an estimated 10% of the wells crossed lease boundaries, usually from the edge of the filed into the producing formation.[172]

However, the rotary rig has certain disadvantages. First, when injecting water and early mud mixes into the well to flush-out drill cuttings, many times these fluids migrated into the formation, damaging or destroying the well.[173]

Second, sometimes the rotary bit would drill completely though the oil or gas bearing formation, and the driller would be unaware of that fact, leaving the oil and gas undiscovered due to the oversight.[174] Cable tool drilling

168. *Id.*

169. BRADLEY, *supra* note 15, at 1122.

170. WILLIAMSON, *supra* note 52, at 29.

171. BRADLEY, *supra* note 15, at 1122.

172. CLARK & HALBOUTY, *supra* note 14, at 281.

173. WILLIAMSON, *supra* note 52, at 29. This problem still occurs from time to time, and drilling contractors are very careful with regard to the composition of their drilling muds and fluids. Fluid intrusion into the formation is referred to by engineers and geologists as "skin" damage. BRADLEY, *supra* note 15, at 1121-32 (noting also that water or mud without sufficient density would flow into the producing formation, damaging the productive capacity of the well).

174. WILLIAMSON, *supra* note 52, at 29.

allowed the operator to be much more aware of any oil and gas zones, shows, or intrusions into the wellbore.

XV. Permian Basin Lithology and Development

Of the two Sub-Basins, the Delaware, the western most Sub-Basin, is the deepest.[175] Due to the depths, the shale formations, and the longer horizontal components of these wells, the drilling rigs generally require more horsepower than in the Midland sub-basin or other unconventional fields.[176] The Midland Basin is somewhat shallower that the Delaware. Some geologists attest that the rock or shale in the Midland Basin is a bit better quality than that in the Delaware.[177]

In both basins, the Wolfcamp shale proves to be one of the more productive for developers. In many areas, the Wolfcamp formation will be subdivided into units, with four to six possible Wolfcamp zones.[178]

Permian Basin wells are generally 4,000 to 10,000 feet deep, with the Wolfcamp shale being 700 to 4,000 feet thick.[179] Average lateral length is roughly 7,550 feet, more than one horizontal mile.[180]

Some developers claim that up to a dozen potential pay zones exist in the Delaware Basin.[181] Because of the geology, some geologists describe the Permian Basin geology as a layer cake of stacked potential producing formations.[182]

Because of the nature of the geology, drillers can locate multiple wells at one surface location (or "pad") and drill from that site to different depth

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175. U.S. GEOLOGICAL SURVEY, *supra* note 13.

176. As the laterals get longer, engineers note that more horsepower is required for drilling, and in general laterals are 27% longer today than they were three years ago. Press Release, Rystad Energy, Impact of Downturn on Shale Development: Permian Success Story (June 20, 2017), http://www.rystadenergy.com/newsevents/news/press-releases/2017-annual-oil-recoverable-resource-review [hereinafter Rystad Energy Press Release].

177. Interview with geologist, Matador Resources, Dallas, Tex. (Jan. 2015).

178. The names of these formations are Wolfcamp A, B, C, and D, with some zones subdivided. *See* U.S. GEOLOGICAL SURVEY, *supra* note 13.

179. The porosity is roughly 4% to 12%, with little permeability. *See generally* Peter Blomquist, *Wolfcamp Horizontal Play, Midland Basin, West Texas*, SEARCH & DISCOVERY (Nov. 28, 2016), *available at* http://www.searchanddiscovery.com/documents/2016/10890blomquist/ndx_blomquist.pdf.

180. Rystad Energy Press Release, *supra* note 176.

181. These include the Avalon, Bone Spring (1, 2, and 3), plus the Wolfcamp series. Blomquist, *supra* note 179.

182. Ed Brooks, *US Prospectors Feast on a Shale Oil 'Layer Cake'*, FINANCIAL TIMES, Nov. 2016, at 17.

horizons. This procedure reduces surface damage and substantially increases drilling efficiency since a series of wellbores can be drilled by skidding the rig a few feet in one direction or another on the pad.

Maximizing efficiencies and minimizing costs of surface facilities—such as pipelines, tanks, separators, and compressors—on the pad can begin at the design stage.

XVI. Recent Technological Developments

Historically, as with the Santa Rita #1 well, developers in Texas drilled vertical wells into "reservoir rock." These are formations that had the requisite porosity and permeability to allow hydrocarbons to accumulate for the thousands or millions of years necessary to trap a commercial accumulation of oil or gas. It was not uncommon to drill multiple dry holes, even in producing fields and using the latest geological data and geophysical interpretation.

The reservoir rock also had to include a trap, generally a fault or stratigraphic cap rock to keep the hydrocarbons from escaping.

Over the last ten years, drilling and fracing technology advanced to the extent that wells now can be drilled and completed in the "source rocks," the formations in which the hydrocarbons were originally trapped. The source rock was previously non-commercial because it lacked permeability and in many cases consisted of shale. The shale now can be hydraulically fractured with pressurized fluids and proppant.

The "layer cake" nature of the Permian Basin allows the developer to develop multiple source rock formations from one surface pad, increasing efficiency and decreasing water disposal and hydrocarbon transport costs.

As drilling and completion attempts evolve, developers are finding that longer horizontal laterals are proving more productive and economic. Measurement while drilling ("MWD") technology allows the operator to track the position of the drill bit as it bores holes thousands of feet from the entry point. In addition, sensors can detect if the drill bit is in the target shale, or if it has deviated out of the source rock.

Logging technology has also evolved where the lateral section can be logged to determine if any faults exist, which may impact frac performance. The logging technology can also be used to determine the characteristics of the target formation which allows the operator to design an effective fracturing program.

With regard to fracing, the companies are generally finding that the more sand used per horizontal foot, the better the well performance. Sand from

Wisconsin, generally referred to as Northern White, has been the preferred sand due to its spherical nature and the grain strength which keeps formations propped open and allows oil or natural gas a pathway to the wellbore.

Local sands have been used in the Permian Basin, but generally have been somewhat less effective, although the cost of the local sand is usually lower and access to quick deliveries is greater. From an economic standpoint, in recent times operators have figured that for roughly each incremental $1 worth of sand the return is $5 to $10, making a compelling case for increasing sand intensity.[183] Five years ago, select wells in West Texas used roughly 20 railroad hopper cars of sand. Today it is not uncommon for a well to use a "unit train," a 100-hopper car train a mile long.[184]

Rystad Energy, an energy consulting firm, conducted a Permian Basin well survey of changes in well characteristics between the first quarter of 2014 and the first quarter of 2017.[185] The results are a stunning snapshot of productivity enhancement for those who do not follow the industry closely:

- Laterals have increased in length by 27% over the 3-year period;
- Proppant intensity per foot has roughly doubled over the 3-year period;
- Fluid intensity per foot has roughly doubled;
- The 30-day initial production rate bbl/d for oil increased 30%; and
- The oil estimate ultimate recovery has increased by 106%.

Other studies indicate similar trends.[186] During a four-year period ending in the third quarter of 2017:

- The median length of the perforated downhole interval increased 37% in the Delaware Basin;

183. Dan Steffens, Chief Executive Officer, Energy Prospectus Group Luncheon, Dallas, Texas (May 2017).

184. *Id*.

185. Rystad Energy Press Release, *supra* note 176.

186. DrillingInfo Consulting, *US Production Key Metrics*, EIA.GOV (2017), http://www.eia.gov/petroleum/workshop/crude_production/pdf/Drillinginfo_USProduction.pdf.

- The median amount of proppant intensity (pounds per foot) increased 261% in the Delaware Basin;
- The median length of the perforated downhole interval increased 26% in the Midland Basin; and
- The median amount of proppant intensity (pounds per foot) increased 76% in the Midland Basin.

Numerous operators continue to study proppant use and fracture systems. To be successful, primary, secondary, and tertiary fracture systems need to remain open. Different size mesh sands are being investigated to maximize the amount of reservoir surface area exposed, with the goal of maximizing the ultimate recovery from the unconventional rock.[187] The mix of technology to optimize the economic recovery expected from drilling a well can become quite complex.

As a result of the longer laterals, more proppant and fluid, and enhanced completion techniques, efficiencies are increasing, with wells yielding much more oil and gas than early completion attempts. According to some estimates, the estimated ultimate recovery of oil has increased by over one-hundred percent in the last three years.[188]

XVII. Future Technological Challenges

One of the major ongoing technical issues with regard to Permian Basin development is water sourcing for fracturing operations as well as the disposal of saline produced water once the wells are in operation. Many Permian Basin wells produce five to ten barrels of brine water for every barrel of oil, and that water must be handled and disposed of in an environmentally-friendly manner.

As laterals become longer, and the amount of sand or proppant increases, more fluid is needed in the fracturing operations. Many times the saline water from produced-water operations will not optimize the frac process and thus cannot be utilized. As a result, many operators are scrambling to find water of acceptable quality for their fracing operations.

In addition to sourcing water, the number of frac crews and rigs available during the industry downturn has been less than optimal. The frac process is

187. There is an increasing focus on measuring cluster fracing performance, trying to design the frac to optimize reservoir stimulation. The number of factors involved which impact stimulation is substantial. Managing these correctly offers the ability to substantially increase returns.

188. *See* Rystad Energy Press Release, *supra* note 176.

extremely demanding on equipment, and margins in the business have not allowed many operators to replace and upgrade their fracing fleet to keep up with the ongoing demand.

Sourcing and delivering proppant sand "the last mile" to the well site is also an issue, although recent temporary storage facilities that can be constructed on site might reduce this technological hurdle. Frac sand comes in various sizes, and the mix and sequence of injection create additional challenges to the operator seeking to optimize completion operations.

XVIII. Conclusion

Drilling and completion efficiency in the Permian Basin continues to improve as technology evolves in a rapid manner. Over the last decade, a massive amount of wealth has been created for mineral owners, companies, and the nation as a result of these advances. In addition, thousands of new, well-paying jobs have been created.

The 1812 Brothers Grimm Tales involved a King who was told that a miller's daughter could spin straw into gold. Unlike the fable, Permian Basin developers did not need Rumpelstiltskin to accomplish the seemingly impossible task. Technology has allowed areas which had been abandoned due to marginal economics to be converted into some of the most promising prospects on the face of the earth. The technology to spin straw into gold has been revealed at last.