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NATURAL GAS, WITH INCIDENTAL REFERENCE TO OTHER BITUMENS.*

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INTRODUCTORY.

Natural Gas is one of the forms of bitumen or hydrocarbon found in Nature, and cannot well be discussed without reference to other forms, such as petroleum, maltha, asphaltum, and the like.

SECTION I.

HISTORICAL SKETCH OF BITUMEN AND ITS SURFACE INDICATIONS.[1]

History fails to record when the first discoveries of bitumen were made by the human race.

It is mentioned many times in the Bible.[2]

The Greek geographer Strabo speaks of the commerce carried

* Presented at the meeting of the Section of Mining and Metallurgy, held Tuesday, April 9, 1912.

[1] The Tenth Census of U. S., vol. x, chap. i, gives elaborate historical references of bitumen by S. F. Peckham. *Ibid.*, chap. vii, bibliography of bitumen. "Petroleum and its Products," by Redwood, vol. i, sec. i, gives a long historical account of bitumen. The Eleventh Census of U. S. gives elaborate "History of the Use of Natural Gas in U. S."

[2] Genesis, xi, 3; II Maccabees, chap. i, verse 19.

on to supply the Egyptians with bitumen for the purpose of embalming the dead.

Centuries before the Christian era, Baku was a resort for the fire worshippers of Persia and India, the inflammable gases issuing from the ground being made use of in their ceremonies, and every year thousands of pilgrims travelled to the temples on the peninsula of Apsheron to worship the holy eternal fire.

These pilgrims,[3] in later years, arrived in diminishing numbers until 1880, when the Russian Government put a stop to their entry.

At Surakhany, on the eastern edge of the Baku oil field, stands a historic monument or temple on a site visited by Parsees for no less than 2,500 years. Natural gas was led through masonry channels to chimneys at its four corners and burned; also to altars where burnt sacrifice was made.

The Hindoos in the Rangoon district of India long used petroleum to heal disease, to preserve timber, and to cremate the dead.

At the town of "Self-flowing wells,"[4] in western China, natural gas has been used for evaporating brine from time immemorial.

In 668 A. D. petroleum[5] and asphaltic substances were offered to the Court of the Emperor Tenji from the province of Echigo, Japan.

In the same province the utilization[6] of natural gas was projected in 1613.

Sir Walter Raleigh visited[7] the pitch lake of Trinidad in March, 1595, and recorded that he saw "abundance of stone pitch." And in recent years Peckham[8] has reported: "As the bitumen rises in the centre of the so-called lake it is inflated with gas . . . . the gas cavities are of all sizes, some of them very large, and in the aggregate occupy, at a rough estimate, from one-third to one-half the volume of the pitch."

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[3] "The Oil Fields of Russia," by A. Beeby Thompson, pp. 96, 97.

[4] Tz-lin-ching, Province of Szchnan. See *Eng. and Mining Journal*, vol. 69, 1900, p. 193.

[5] Bulletin No. 61, Jan., 1912, Am. Inst. Mining Engineers, p. 104.

[6] *Ibid.*, p. 127.

[7] "Petroleum and Its Products," by Redwood, vol. i, p. 96.

[8] *Am. Journal of Science*, 4th series, vol. i, p. 193.

In the regions of Trinidad[9] and Venezuela, where pitch lakes occur, natural gas is continually forcing up cones of pitch, and they break at the apex and gas issues that may be lighted and will burn sometimes for days.

This phenomenon may be observed not only in the pitch lakes but in the surrounding land asphalt and swamps.

Fig. 1 is a view in Trinidad of typical cones forced up by gas pressure.

FIG 1.

Typical cones formed by gas, Trinidad, B. W. I.

On November 4, 1911, about midday, a fisherman noticed signs of disturbance[10] in the sea off Erin Point, Trinidad.

About 6 P.M. a great column of fire shot up from the water. The principal gas eruption lasted 15 to 20 minutes. There were intermittent flashes of flame during the night.

The next day it was found an island of about 2½ acres had been formed. A landing party found the place still warm, and by laying down boards were able to examine two cones, 12 to 15 feet high, from which gas was escaping. The air was saturated with the odor of sulphur and oil.

The aborigines of our own country were acquainted with

[9] Letter of Arthur Knapp, July, 1911.

[10] Account given in *New Orleans Times-Democrat*, Nov. 26, 1911.

petroleum and natural gas springs. The French [11] commander of Fort Dusquesne (now Pittsburgh, Pa.) wrote in 1750:

> While descending the Allegany we were invited by the Chief of the Senecas to attend a religious ceremony of his tribe. We landed, and drew up our canoes on a point where a small stream entered the river. The tribe appeared unusually solemn. We marched up the stream about half a league, where the company, a large band, it appeared, had arrived some days before us. Gigantic hills begirt us on every side. The scene was really sublime. The Great Chief then recited the conquests and heroism of their ancestors. The surface of the stream was covered with a thick scum, which, upon applying a torch at a given signal, burst into a complete conflagration. At the sight of the flame the Indians gave forth the triumphant shout that made the hills and valleys re-echo again. Here, then, is revived the ancient fire worship of the East; here, then, are the children of the sun.

The existence of natural gas [12] was well known to the earliest explorers of the Kanawha Valley, West Virginia.

In 1775 Washington, while on a visit here to locate lands granted him for his military services, set apart and deeded to the public forever a square acre of land on which was located a "burning spring." Through some informality his intention in this gift was frustrated.

In this same valley, in 1808, and soon after in the valley of the Muskingum, wells were drilled for brine and many primitive salt works were put in operation.

The method and tools for drilling wells evolved here were the progenitors of the method and tools now used in sinking oil and gas wells in similar formations all over the world.

The description [13] of an oil spring near Cuba, New York, made in 1833, says:

> Gas is constantly escaping through the water, and appears in bubbles upon its surface; it becomes much more abundant and rises in large volume whenever the mud at the bottom is stirred by a pole.

In 1833 Dr. Hildreth [14] gave a very entertaining description of the salt works of Ohio and West Virginia, and of the wells

[11] Henry's "Early and Later History of Petroleum."

[12] West Virginia Survey, vol. i (*a*), part i, page 2.

[13] Benjamin Silliman, Sr., vol. 23, p. 97, Jan., 1833, *Am. Journal of Science.*

[14] Dr. S. P. Hildreth, *Am. Journal of Science,* vol. 24, July, 1833, p. 46.

says: "All salt wells afford more or less of this interesting gas [natural gas], an agent intimately concerned in the free rise of the water, and universally present where salt water is found."

Fredonia, N. Y., has the distinction[15] of being the first place in America where natural gas was used for illumination. When this village was incorporated, its seal was designed to show a gas fixture.

In June, 1825, General Lafayette witnessed the illumination of this village with it after it had then been in domestic use some three or four years.

So far as has been ascertained, the first[16] use of natural gas in manufacturing in America was in "boiling salt" in the Kanawha Valley. Here, in 1841, William Tompkins, while boring for salt, struck a large and steady flow of gas, which was strong enough to force the salt water into a reservoir, from which it could be distributed to his furnace pans. He extemporized a gas holder from a hogshead placed over the salt water reservoir, into which he conveyed the escaping water and gas, the water falling into the reservoir, and the gas was conveyed through a pipe to the furnace and produced an intense heat under the whole row of kettles.

In 1843 a well near the Tompkins well, at a depth of 1,000 feet, threw a column of salt water and gas 150 feet high, and was the first "roarer" on record; and

> For many years[17] this natural flow of gas lifted the salt water 1,000 feet from the bottom of the well, forced it a mile or more through pipes to a salt furnace, raised it into a reservoir, boiled it in the furnace, and lighted the premises all around at night.

Knowledge of the existence[18] of oil and gas in the rocks of Ohio resulted largely from the search of the pioneers for that necessary article, common salt. Thus a well drilled in 1814, near the village of South Olive, Noble County, for brine, found such a pressure of gas that it threw salt water and some oil to a height of from 30 to 40 feet, and these eruptions continued for a period of 25 years. About the same time both oil and

[15] Dr. Orton, p. 494, *Bulletin N. Y. State Museum*, vol. 6, No. 30.
[16] Eleventh Census, "History of the Use of Natural Gas in U. S.," p. 507.
[17] Quoted from West Virginia Geological Survey, vol. i, a, p. 11.
[18] Geological Survey of Ohio, fourth series, Bulletin 1, p. 31.

gas were discovered in Washington County. Similar results were secured at many points in the southeastern part of the State, but the oil and gas were regarded as a nuisance. The former ruined the brine for the manufacture of salt, and the latter was regarded as too dangerous for use.

At Findlay, Ohio, natural gas was found in October, 1836, in digging a well. In 1838 gas from another water well was conducted by wooden tubes into a fireplace and burned from an old gun barrel. This continued in use for over forty years.

It is interesting to note that evidence of this kind led later to tests at several points, with the result that valuable pools of oil were discovered, and finally the great Trenton limestone field itself.

At Burksville,[19] Kentucky, in 1829, a well drilled for salt struck oil at 300 feet. The drilling tools were lifted out of the well by the force of the gas and a column of oil was thrown to the top of the trees.

About 1841, while some work for the removal of McGrew's Shoals, Tombigbee River, Alabama, was in progress, a well was drilled and oil struck at a depth of 365 feet, "which boiled[20] up very similar to the effervescence of a boiling pot."

Natural gas shows with salt water at the Central, Lower and Upper salt works and the sulphur springs at Jackson, all in Clark County, Alabama.

The Alabama geological[21] reports refer to the salt works, but do not mention the presence of natural gas.

I believe this showing of gas is a "marker" for a nearby oil and gas field in this formation. There has lately been natural gas developed in paying quantity in a lower formation in Fayette County.

The costal plains[22] of Louisiana and Texas contain a vast number of gas springs and a few showings of oil.

The settlers[23] in Texas as far back as 1820 knew of petroleum springs, "and they resorted to the places where it

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[19] Sixteenth Annual Report U. S. Geol. Survey, part iv, p. 376.

[20] Said to be from Niles' National Register, Aug. 14, 1841.

[21] Report on the Geology of the Costal Plain of Alabama, by E. A. Smith.

[22] Bulletins 184, 212 and 429, U. S. Geological Survey, treats largely of the Costal Plain.

[23] "Petroleum and Its Products," by Redwood, vol. i, p. 90.

oozed from the ground as a black and pasty mass to gather it, though their only use for it was to grease the axles of their wagons, and to protect their implements from rust."

A notable one of these places was at Sour Lake, Hardin County, where the occurrence of oil, asphalt, and gas had long been known.

Fig. 2 is a view of the Sour Lake; the spots of rippling water are caused by gas bubbling up, but this has now ceased, as the gas pressure has been reduced by drilling wells in the vicinity. The first attempts made in drilling here were failures, although promising indications were found.

FIG. 2.

Sour Lake, Texas.

After 1901, with increased drilling experience and better appliances, Sour Lake was developed as an oil field, and some 25,000,000 barrels of oil have been produced since.

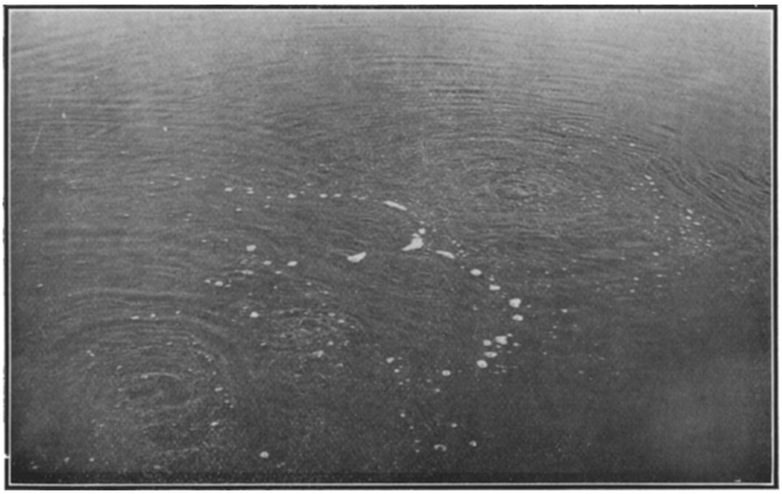
A small gas spring highly impregnated with sulphuretted hydrogen attracted attention to Spindle Top, a mound near Beaumont, Texas. Prior to 1899 several attempts were made to prospect this mound, but were failures for lack of experience and proper drilling machinery. In 1900 Captain A. F. Lucas drilled a well to prospect for sulphur to a depth of about 600 feet and got a good showing for oil.

A second well, with heavier rotary drilling machinery and more experienced drillers, got oil at between 1,100 and 1,200 feet and became the famous Lucas gusher.

The Spindle Top pool covered about 250 acres and has since yielded some 40,000,000 barrels of oil.

Attempts were made as early[24] as 1869 to drill for oil along the Gulf border, but oil in commercial quantity was not obtained until the Lucas gusher was developed in January, 1901.

FIG. 3.



Gas spring in Lake Felicity, La. This is typical of a large gas spring or escapement in water.

In 1903 I started out to look for oil indications along the Gulf border. I found true gas springs very abundant in Terrebonne Parish, Louisiana.

Fig. 3 shows a gas spring[25] in Lake Felicity, near its west shore. I should say that there was not less than 250 cubic feet of gas escaping per hour. This is typical of a large gas spring or escapement occurring in water.

The guide who showed me this place (Mr. Oscar Price) said that he had known of many of these escapements for over

[24] Geological Survey of Louisiana, Report of 1899, p. 126.

[25] About in Sec. 25, Twp. 20, S. Range 19 East, Terrebonne Parish.

forty years, and they were much the same as to quantity of gas then as now, but that the vents changed somewhat in appearance from time to time, sometimes the gas escaping all at one place, and sometimes at several places, but not very far apart.

Fig. 4 shows a typical gas escapement in a field.

I am confident that such persistent gas springs as those mentioned, with hundreds of others of the same kind that occur

FIG. 4.

Blanchard's plantation, Bayou Terrebonne, La. Typical view of gas escapement in a field.

in that vicinity, mean very extensive and productive oil-and-gas-bearing sands in Terrebonne Parish.

Abundance of gas can be obtained here, in places, by stirring up pools of water from the bottom, as shown by Fig. 5. I lighted this gas and the flame blistered the paint on the boat.

I visited this place several times and no gas could be seen unless the water was agitated or the bottom stirred. Such gas showings, I think, are due entirely to decaying vegetation near the surface, and are not fed from a deep source like the permanent gas springs mentioned.

The earliest settlers[26] of eastern Kansas learned from the Indians that "oil springs" existed in a number of places. Some were counted of wonderful efficacy by them, and the "medicine men" there obtained material to use in their various forms of "practice." These springs were principally in Miami and Wyandotte Counties. In Cherokee County, "Tar Creek" received its name from petroleum indications. I watched oil and gas developments in Kansas from 1895 and drilled over 200 wells. But one surface showing of oil came to my knowl-

FIG. 5.

Gas being stirred up by agitation.

edge, and that was about six miles east of Chanute, where I saw a small showing of thick oil found by a farmer in digging for a cellar. People came to me many times to go and see gas springs. This occurred usually after a dry spell followed by a heavy rain, when the ground was filling up with water. Then crawfish holes in the bottoms, and mole and insect holes in the uplands, would, when conditions were right, show a bubbling that looked the same as gas, but would not flash or light.

In Oklahoma[27] burning springs are found in several parts

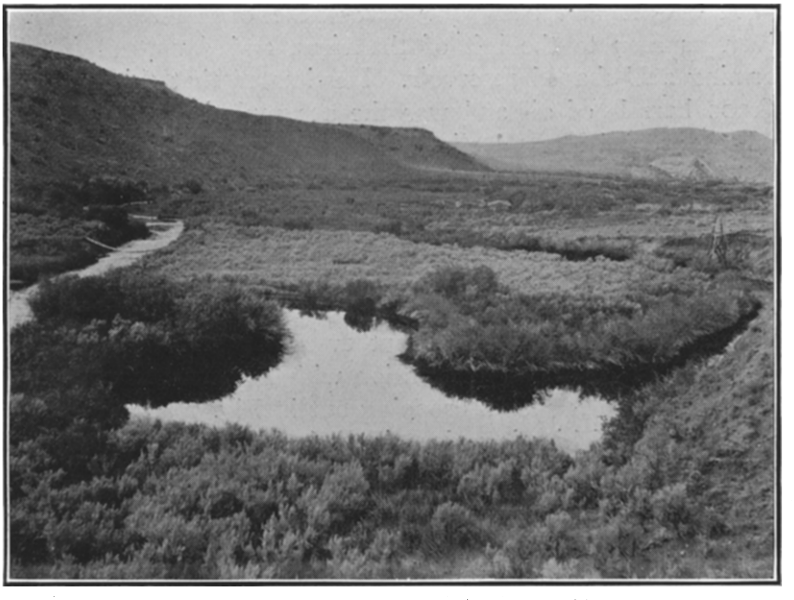
[26] Haworth in the University Geological Survey of Kansas, vol. i, p. 232. *Ibid.*, vol. ix, p. 25.

[27] Proceedings of the Natural Gas Association of America, vol. ii, p. 118.

of the State, the most notable being in northeastern Pittsburgh County, some twenty miles northeast of McAlester. At this point gas escapes over an area of perhaps 300 square feet. It issues from crevices in the soil and among the rocks, and when set on fire often continues burning for weeks.

In the summer of 1899 I visited the then territory of Wyoming [28] and saw many oil and gas springs. At Lander

FIG. 6.



View of the Little Pope Agie Valley, about ten miles southeast of Lander, Wyoming, in Twp. 32 N., R. 99 West.

I met an old-time trapper who had lived among the Shoshones. He told me that the Indians knew of many oil and gas springs, and called them "the place of the Big Medicine."

Fig. 6 is a view of the Valley of the Little Popo Agie.[29] At the right is a derrick over the No. 1 Murphy Well, said to

[28] Sixteenth Annual Report, U. S. Geol. Survey, part iv, p. 382. Annual Report Territorial Geologist, 1886, Laramie, Wyo. Annual Report Territorial Geologist, 1888, Cheyenne, Wyo. Bulletin 119, U. S. Geol. Survey, p. 64. University of Wyoming Bulletin No. 14, Oct., 1893, p. 161. University of Wyoming Bulletin, No. 2, Petrol. Series, Jan., 1897.

[29] About 10 miles S. E. of Lander, in Twp. 32, N., R. 99 W.

be 300 feet deep. At this place the oil and gas still seeped from the ground, as well as leaked from the well.

About 1833 Captain Bonneville[30] "made search for the great tar springs, one of the wonders of the mountains, the medical properties of which he had heard extravagantly lauded by the trappers." His description points to this place, and when they found it "the men immediately hastened to collect a quantity of it to use as an ointment for the galled backs of their horses and as a balsam for their own pains and aches."

A cut-off had been dug across the original bend of the river, as seen to the left of the view, and dams put in, thus forming a U-shaped reservoir. I estimated that this contained 18,000 barrels of oil and was the accumulation of nine years' leakage around No. 1 well.

This oil made a great trap for ducks, geese, and other birds, for if they lit on its surface they could not rise again out of the thick oil; also, many sheep were lost in it. Before, and for a time after, the advent of the Union Pacific, oil from this place found profitable sale for lubricating purposes to the railroad, ranchers and mills, but eventually practically all this trade was lost through competition with Eastern refined oils.

An oil sand is shown cropping out in Fig. 7 above the man, and in front of him is a deposit made by oil seepage. At the foot of the slope was a strong gas escapement.[31]

In the early days of California[32] the Catholic fathers utilized asphaltum for roofing their missions and other buildings from nearby deposits, and from time immemorial the Indians had known of and used this mineral.

The first discovery of bitumen at Summerland,[33] California, was where there was a fumarole, some twenty feet in diameter, from which warm carburetted and sulphuretted hydrogen gas escaped. No vegetation grew on this place. The Spaniards had a legend that a man was killed there, which, according to them, accounted for the fact that nothing grew there.

A pipe driven in this spring and reduced to two inches

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[30] Washington Irving's "Bonneville," p. 142.

[31] In Fremont County, Wyoming, about forty miles due east of Lander.

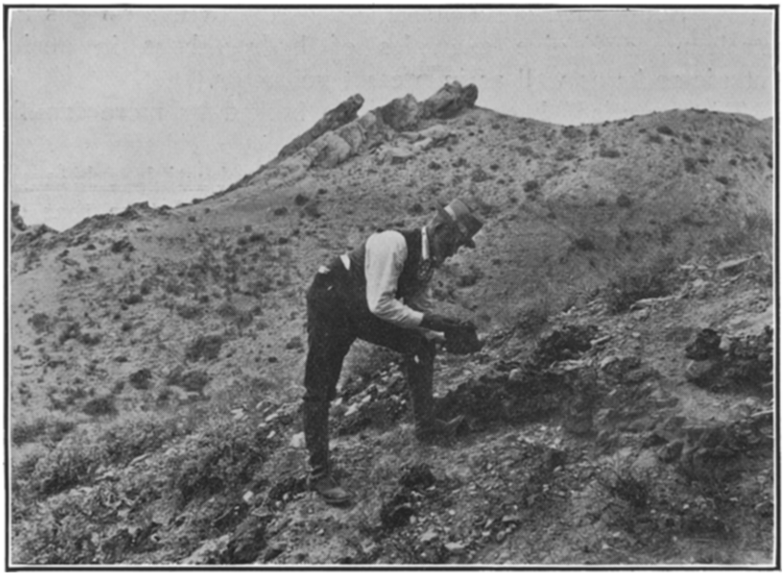
[32] "Petroleum in California," by Redpath.

[33] Bulletin No. 16, State Mining Bureau, 1899, p. 62.

gave pressure and quantity enough of gas to make a flame ten feet long. The following up of this discovery led to drilling submarine oil wells from a wharf. Cooper says:[34] "Frequently gases are seen to ascend from the bottom of streams and pools of water, and that it occurs in many places in California."

I have shown a wide geographic distribution of bitumen, and particularly of natural gas. It is one of the most difficult

FIG. 7.



Fremont County, Wyoming, about 40 miles due east of Lander. Oil sand croppings and hardened oil made by seepage.

facts of history to understand the extreme slowness with which the human race developed the industrial use of bitumens, especially that of oil and gas. It is only about thirty years since natural gas began to come in use on a large commercial scale.

Time forbids that I should dwell longer on the history and surface indications of bitumens, so I will pass to the next part of my subject.

[34] Bulletin No. 16, State Mining Bureau, 1899, p. 83. See Bulletin No. 321, U. S. Geol. Survey, part i, p. 11 and quotation bottom page 13.

SECTION II.

ORIGIN OF BITUMENS.

Many theories have been put forward to account for the origin of bitumens in the crust of the earth. There are two main groups of these hypotheses, one ascribing an inorganic and the other an organic origin.

The celebrated chemists[35] Bertholet and Mendeljiff pointed out (in 1869 and 1877) possible chemical reactions under which hydrocarbon compounds could be generated in the earth's interior. Some advocate a volcanic origin[36] of natural gas and petroleum, and give examples of hydrocarbons in ancient plutonic rocks as well as in present volcanoes.

The organic[37] hypothesis can be backed by more familiar facts than those just outlined.

Natural gas and other bitumens are combustible substances, and every other substance that we know in Nature that can be burned is organic in origin.

Chemists have produced unmistakable members of the petroleum group, including illuminating oil, lubricating oil, benzine, and paraffin, from the distillation of fish oil, and in such distillations some gas is given off.

By observation[38] we know that natural or marsh gas is a product of slow primary decomposition at low temperature of organic matter contained in sediments, and so is from an organic source. These decompositions were extremely slow, and the present pools of oil and gas are the accumulation of enormously long periods of time.

I think it is safe to say, from our present knowledge, that some bitumens may come from an inorganic source, but by far the greater amount come from terrestrial and marine vegetation and organisms.

We might well adopt for our conclusions the translation of an inscription placed over a meteorite that fell centuries ago in Germany: "Many men say many things; every one says something; nobody gives a satisfactory account."

[35] Tenth Census, vol. x, p. 59.

[36] *Journal Can. Min. Inst.*, vol. iii, pp. 68–89.

[37] Adapted from Dr. Orton, *Bulletin N. Y. State Museum*, vol. 6, No. 30, p. 426.

[38] U. S. Geol. Survey, Eleventh Ann. Rep., part 1, p. 613.

SECTION III.

THE GEOLOGY OF BITUMEN.

With Especial Reference to Natural Gas.

In the gaseous, liquid, and solid forms bitumen is one of the most widely distributed of substances. Its geological limits of profitable production include the whole range of unaltered strata, from the Cambrian rocks to the most recent series of the Quarternary system.

The publications of the United States Geological Survey, with those of the several States, and of the geological societies, give a wealth of detail of the geology of every locality in the United States where oil and gas are now produced in paying quantity. These works should be consulted on geological questions. Many of them can be had for the asking, and for those that are sold the price only covers the cost of printing and mailing.

Geology is more of a historic than exact science, with but few demonstrations of the sort that carry mathematical certainty, and the wise geologist confines his teachings to the known, without attempting the rôle of a prophet.

The principles [39] of geology are not visionary; they are supported by a great multitude of harmonized facts. The maps and sections in the publications mentioned show this to be the case. But the geologist does not know whether a sand [40] exists at a given spot beneath the surface, nor whether, if there be a sand, it holds gas or not, nor whether, if the gas be there, it will flow toward a drill hole. But this ignorance of facts, all of them out of sight and out of reach before experiment, he shares with everybody else. No one, absolutely no one, can know such facts before a well is bored.

Rocks are of many kinds, and as the paying pools of gas are found only in those of sedimentary origin, I will refer to this kind only.

Such rocks are composed of the detritus of older rocks and carried by water, air, and ice in motion into lakes and seas,

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[39] Adapted from J. P. Lesley's letter of transmission, Penna., Second Geological Survey, vol. iii.

[40] Sand is a general term, and includes sandstone and limestones that carry oil or gas in paying quantity.

forming gravels, sands, and clays which are later consolidated into conglomerates, sandstones, and shales.

In smaller portion the materials are also carried in solution, and the deposits are then called organic, if formed with the aid of life, and chemical without this aid. Organic and chemical rocks are limestones, cherts, gypsums, peat, lignite, and coal.

Much terrestrial and marine vegetation with marine, brackish, or fresh-water organisms is thrown down with such deposits, forming, in the aggregate, a vast amount of carbonaceous material sufficient to account for all the gas and other bitumens found in Nature.

These sedimentary rocks are mostly deposited in layers or beds originally in a horizontal position, or nearly so, and which can easily be separated. These layers are called strata, and the deposits are said to be stratified.

Most of such rocks grew up in the sea, some cover thousands of square miles, and for the accumulation and growth of these enormous deposits vast periods of time were required.

All stratified rocks can be divided into two general divisions with reference to their porosity—the permeable and the impermeable. Some rocks are freely permeable, others are less so, and still others resist the passage of water so effectually that we call them impermeable.

Conglomerates and sandstones are types of the porous group. Shales and clays represent the impervious series, and are perfect seals when they carry moisture.

Dolomitic and crinoidal limestones, under certain conditions, are also porous, but most of the limestones are impervious.

The porous rocks usually contain water, and when near the surface it is fresh. Sometimes they are dry, or they contain gas only, or they contain oil and gas, or they contain oil, gas, and water, and such rocks are referred to as reservoir rocks, and I will describe them more particularly later.

When water is associated with oil or gas or nearby strata below or above them, it is invariably impregnated with salt or sulphur, or both. Outside of oil and gas territory, potable water may be got at considerable depth, as at Charleston, S. C., where warm potable water (99½° F.) is obtained between 1,950 and 2,000 feet.

Porous rocks, which have become a reservoir particularly of oil or gas, have so become by virtue of the fact that its contents are confined within it by an impervious covering which generally consists of shale or clay carrying some moisture.

By orogenic movements the stratified rocks have been arched up, thrown into waves and crumpled. The crystallization of salt[41] from solution and intrusion of laccoliths has in a few places raised up dome-shaped hills of these rocks, and volcanic plugs and vents have been forced up through them. Such disturbances of original structure have formed anticlinals, synclinals, domes, fault, joint cracks, and volcanic vents, and these variations play an important part in the accumulation and concentration of oil and gas into paying "fields" or "pools."

The fundamental geologic conditions necessary for a profitable accumulation of oil or gas must be:

First. A source of supply, probably from carbonaceous material enclosed in sedimentary strata.

Second. A reservoir rock such as may be found in any porous rock that will allow the passage of fluids between its particles.

Third. A cover of impervious moisture holding rocks to seal and hold the oil and gas from loss by dissipation.

SECTION IV.

CLASSIFICATION OF OIL AND GAS ACCUMULATIONS.[42]

I. Where anticlinal and synclinal structure exists.

(*a*) Strong anticlines standing alone.
(*b*) Well-defined anticlines and synclines alternating.
(*c*) Monoclinal dips.
(*d*) Terrace structures.
(*e*) Broad geanticlinal folds.
(*f*) Overturned folds.

II. Without anticlinal structure.

(*a*) Lenticular sandstones enclosed in shale.

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[41] G. D. Harris in Bulletin No. 429, U. S. Geological Survey, p. 8.
[42] "Economic Geology," by F. G. Clapp, vol. v, No. 6, pp. 503–521.

(*b*) Sandstones that shade into shale.

Both (*a*) and (*b*) are entirely enclosed in shale and not in communication with water under hydrostatic pressure.

III. Domes, or quaquaversal structures.
IV. Sealed faults.
V. Oil and gas sealed in by asphaltic deposits.
VI. Contact of sedimentary and crystalline rocks.
VII. Joint cracks.
VIII. Surrounding volcanic vents.

The great gas fields come under the first two classes of accumulations, and as the gas associated with the other classes is not of commercial importance I will not refer further to them.

Through the investigations of geologists [43] working in the great Appalachian field the structural or anticlinal theory of the accumulation of oil and gas was evolved.

The three fundamental geologic conditions for the accumulation of oil and gas have been previously stated. In addition to these, for the proper theoretical anticlinal conditions we should have:

Fourth. Water in the porous stratum with the oil and gas.

Fifth. Geologic structure, or a decided slope of the porous stratum.

It cannot be doubted that the fifth condition mentioned,—geologic structure—does play an important part in the accumulation of oil, and particularly of gas, and it is a fact that many gas pools are located along anticlinals and in domes, but the theory is not, in my opinion, of universal application.

To such fields as the theory applies [44] it is of economic importance, and the geologist should be consulted to locate favorable points in advance of any drilling.

Fig. 8 is a well section across the oil and gas trend just east of Chanute, Kansas. The productive oil sand shown at this point is about one-third of a mile wide and 20 to 30 feet

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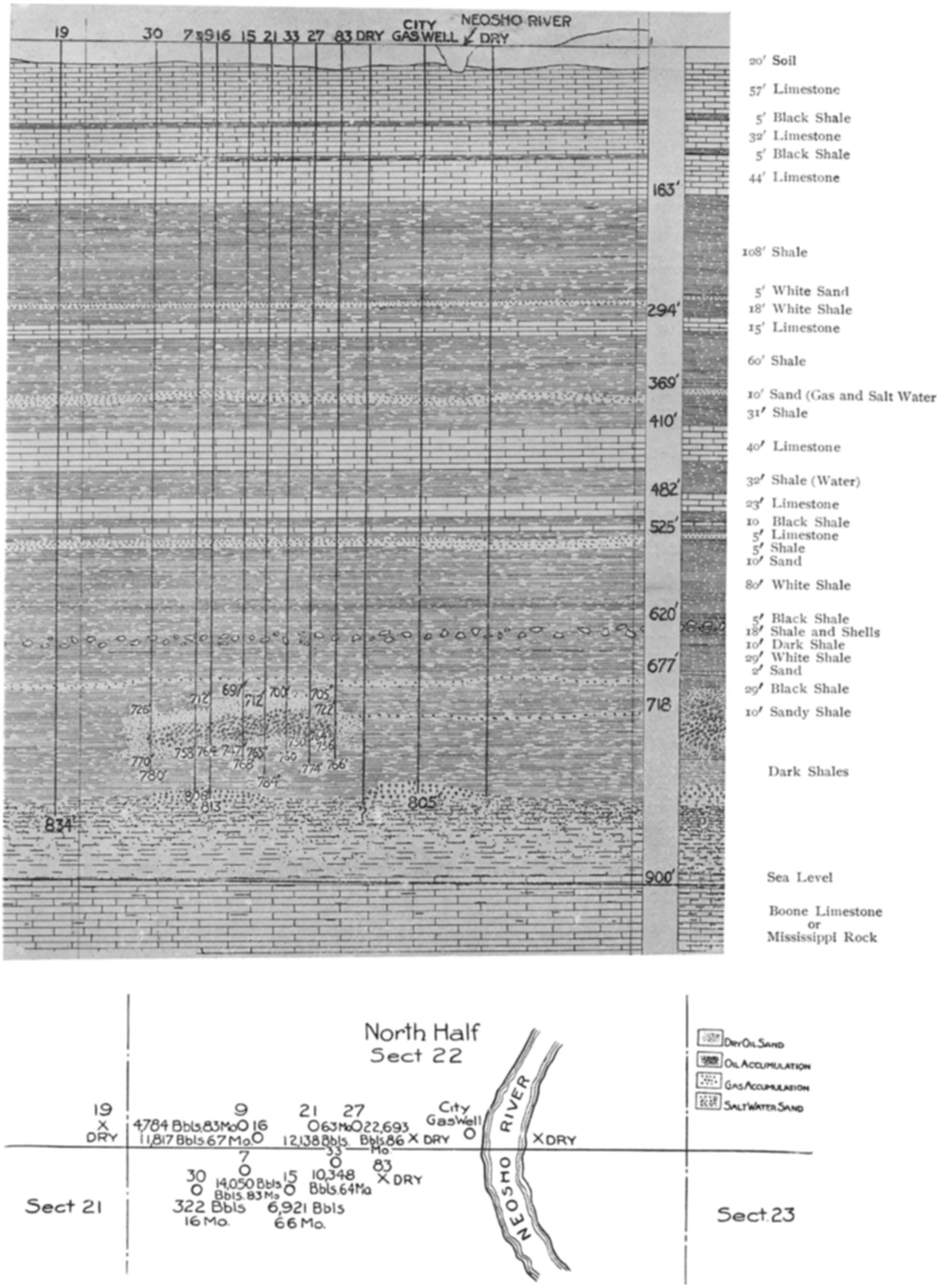
[43] See "History of the Structural or Anticlinal Theory," by I. C. White, West Virginia Geol. Survey, vol. i (a), 1904, p. 48.

[44] West Virginia Geol. Survey, vol. i, p. 60.

FIG. 8.

Plan and section of wells drilled by I. N. Knapp, one mile east of Chanute, Kansas, showing average width of productive oil sand from east to west, total length about three miles north and south. Small spots of gas sand under soil.



thick. The real productive sand is from 10 to 15 feet thick and 700 to 750 feet deep in the level lands along the Neosho River. It varies in width from one-fourth to one-half a mile, and is about five miles long, along the strike of the dip, and practically exactly horizontal in width and length. It is, therefore, not a continuous sheet of sandstone like the Pennsylvania oil sands or Trenton rock. It carries nothing but oil, and does not connect at any place with water-bearing strata, but grades into impervious shales in all directions. The oil is combined with but little gas, and wells will not flow unless drilled deep enough to prick the gas sand if found below.

It is evident that the anticlinal theory played no part in the accumulation of oil in this particular sand.

Below the oil horizon, some thirty to forty feet, and just on top of the salt-water sand, is a gas horizon with occasional spots productive of gas. The southernmost well that I drilled in this trend proved to be a gasser at 781 feet, and the northernmost well, three miles away, a gasser at 780 feet, the tops of the wells being probably within five feet of the same elevation. The gas sands here appear like small sand bars or sand dunes laid down on top of the salt-water sand, which were covered up by mud (the shales) and in time cemented into the rock we find. The gas sand (cuttings from the gas-bearing sandstone) and the salt-water sand (cuttings from the salt-water sand rock) are quite different in appearance. The salt-water sand carries minute particles of mica that are characteristic, and as soon as they appear in the cuttings, even before salt water shows, it is at once recognized that no gas will be obtained at that particular point.

At Altoona, Kansas, my drilling developed gas in two sands having the same relative position as the oil and gas sand at Chanute.

The conclusion is that each oil and gas field must be considered by itself, both from a geologic and operating standpoint. The geologist, operator, or driller expert in one field has to learn the business over again when he goes into a new field.

When a man starts as pioneer in a new field in which practically nothing is known of its geology, with no well records or methods of operating work out, he is up against a pretty hard proposition.

SECTION V.

RESERVOIR ROCKS.

The porosity of rocks,[45] sand, and earth has been the subject of elaborate investigation as to their capacity to hold water, and the rate of flow of water and air through them. It has been shown that if a theoretical sand consisted of perfect spheres of equal diameter, placed at a maximum distance apart, the pore space is 47.64 per cent.; if at a minimum, 25.95 per cent. These percentages hold true, no matter what the diameter is. This proves the pore space is the same in a fine sand as in a coarse one.

If a quantity of common shot be poured in a glass and the open spaces filled with water, the porosity will be found well within the limits given, whether the shot be fine or coarse, and the same is true of common sand.

After the sands of the sandstones were laid down they have been subject to "secondary growth" by the slow deposition of cementing material from circulation of underground waters, thus forming rock and reducing the original porosity in varying degree. The porosity of limestones has also been decreased in similar ways and also increased by solution.

The fractional part of a rock in which there are open spaces or voids determines its porosity. That is, if a cubic foot of rock will hold, when saturated, one-tenth of a cubic foot of oil or water, such rock is said to have a porosity of 10 per cent., for one-tenth of its volume is pore space. If such pore space was filled with gas at 30 atmospheres, then each cubic foot of rock would hold 3 cubic feet of gas at atmospheric pressure.

All rocks are porous in some degree. Even slate of the closest grain will hold some liquid in its microscopic cavities. Those rocks that are so open-grained or porous that, if a hole be drilled into them, they can be drained of their liquid or gaseous contents are called reservoir rocks.

The porosity of the reservoir rocks often extends to great distances. Striking proof of this is supplied in the practical development of many gas fields. In northwestern Ohio,[46]

[45] See papers of F. H. King and C. S. Slichter, Nineteenth Annual Report, Geol. Survey, part ii, 1897–1898.

[46] Geological Survey of Ohio, 1890, p. 88.

according to Dr. Orton, wells separated by intervals of a half or three-quarters of a mile are found to affect each other's flow and pressure to an important degree, and it is also found that areas of several consecutive square miles can sometimes be drained of their gas by a single well.

Underground[47] water may be found in cracks and crevices in rocks, but by far the larger portion exists in the minute pores and openings between the rock particles themselves.

Caves, cracks, or crevices in rock are largely surface phenomena. Below the surface, as the depth increases, the weight of the superincumbent material tends to close any opening, and Professor Van Hise[48] shows that at a depth of about six miles the weight is so great that all rocks become plastic and flow so as to close up even their minute microscopic pores.

A West Virginia well[49] developed gas in the Gantz sand horizon at 2,770 feet, as well as in the "Fifty-foot" sand at 2,840 feet, and a still larger flow was found in the fifth or McDonald sand at 3,115 feet, the hole being completed at 3,300 feet. The Gantz and "Fifty-foot" sands constituted one solid, coarse, pebbly rock, and in order to save all of the gas flows the well was packed in the upper portion of this pebbly stratum. From the great depth of the well it was expected that the rock pressure would rise until it exceeded 1,500 pounds to the square inch, but when shut in the gauge, which began to register rapidly at first, very soon slowed up, and finally stopped at 650 pounds. As the pressure did not rise sufficiently rapid to correspond to the apparent volume of the gas when the gate valve was open, it was concluded that a large portion of the gas was being forced into the porous Gantz and "Fifty-foot" beds and stored therein, the 650 pounds representing the pressure necessary to store in the pores of that rock all the surplus gas produced from the three horizons at that pressure.

(*To be continued.*)

[47] See U. S. Geological Survey Water Supply and Irrig., Paper No. 67, pp. 14–16.

[48] See paper of C. R. Van Hise, Sixteenth Annual Report, U. S. Geol. Survey, part i, 1896, p. 593.

[49] West Va. Geol. Survey, vol. i (a), p. 7. Alonzo Edwards Well No. 1, near Wadestown, Monongalia Co., W. Va.