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THE SALT CREEK OIL FIELD
WYOMING

BY

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THE SALT CREEK OIL FIELD, WYOMING.

By Carroll H. Wegemann.

INTRODUCTION.

The Salt Creek oil field, which produces daily 10,000 barrels of high-grade paraffin oil, is at present the largest proved field in the State of Wyoming. A number of fields more recently developed—such as Grass Creek, Big Muddy, and Elk Basin—are attracting much attention, but so far none of these promises to include an area so large or wells so productive.

The Salt Creek field proper (Pls. I, II, in pocket) includes an area of about 7 square miles lying in Ts. 39 and 40 N., R. 79 W. It is 40 miles due north of Casper and 30 miles southeast of the foot of the Big Horn Mountains. An automobile stage plies between Casper and the town of Salt Creek, which is in sec. 25, T. 40 N., R. 79 W., in the eastern part of the field. Salt Creek may be reached from the north by way of Gillette, on the Chicago, Burlington & Quincy Railroad, or from the towns of Buffalo and Kaycee over roads that are practicable for an automobile, but these trips are long and lie for the most part through open, sparsely settled country. In Salt Creek good accommodations may be had at the hotel, and there is a post office, a general store, and a drug store in the town. The old road ranch and post office at Shannon, in sec. 1, T. 40 N., R. 79 W., are no longer in existence, and only a caretaker lives at the oil camp.

The present report embodies the results of studies made in the field by the writer in 1909, 1910, and 1915, and is the second report published by the United States Geological Survey on the Salt Creek field.[1] In presenting it the author desires to express his thanks for valuable suggestions and criticism to M. R. Campbell, who has had general supervision of the work, and to R. W. Stone, both of whom were in the field during the beginning of the investigation in 1909. The author is also indebted to T. W. Stanton, who visited the field in 1910 and who identified the fossils. In 1909 the writer was

[1] The first report formed a part of U. S. Geol. Survey Bull. 452 and was entitled "The Salt Creek oil field, Natroma County," by Carroll H. Wegemann, 1911.

assisted by Ralph W. Howell and William Mulholland, in 1910 by C. J. Hares, and in 1915 by C. W. Hammen, to all of whom he desires to make grateful acknowledgment.

The section on water in the oil sands (pp. 42–45) was kindly prepared by R. C. Wells and R. V. A. Mills.

The operators and drillers in the field cooperated heartily in the work. Thanks are due especially to N. S. Wilson, H. M. Rathvon, C. A. Fisher, Ambrose Hemingway, and other officers and employees of the Midwest Refining Co., and to W. D. Waltman, manager, Franco Wyoming Oil Co., who supplied maps of the field, logs of the wells, and assisted in other ways; also to E. W. McCrary, R. J. Mosher, J. C. Snook, and many others for maps and valuable information.

This report covers not only the Salt Creek oil field proper, in which the oil is obtained from the Wall Creek and so-called "Lower Wall Creek" sands and the shale that overlies them, but also two adjacent pools, in which the oil is derived from the Shannon sand, which lies 2,000 feet stratigraphically above the Wall Creek. The smaller of these, the Shannon pool (Pl. III), which lies 4 miles north of the town of Salt Creek, produced the first oil found in this region; the larger, the Teapot or Saddlerock dome, lies 10 miles southeast of Salt Creek and has not yet been thoroughly tested, although oil has been struck in it in at least two wells which reached the Shannon sand.

A separate report[1] has been prepared on the Powder River or Tisdale dome, which lies 10 miles west of Salt Creek.

HISTORY OF DEVELOPMENT.[2]

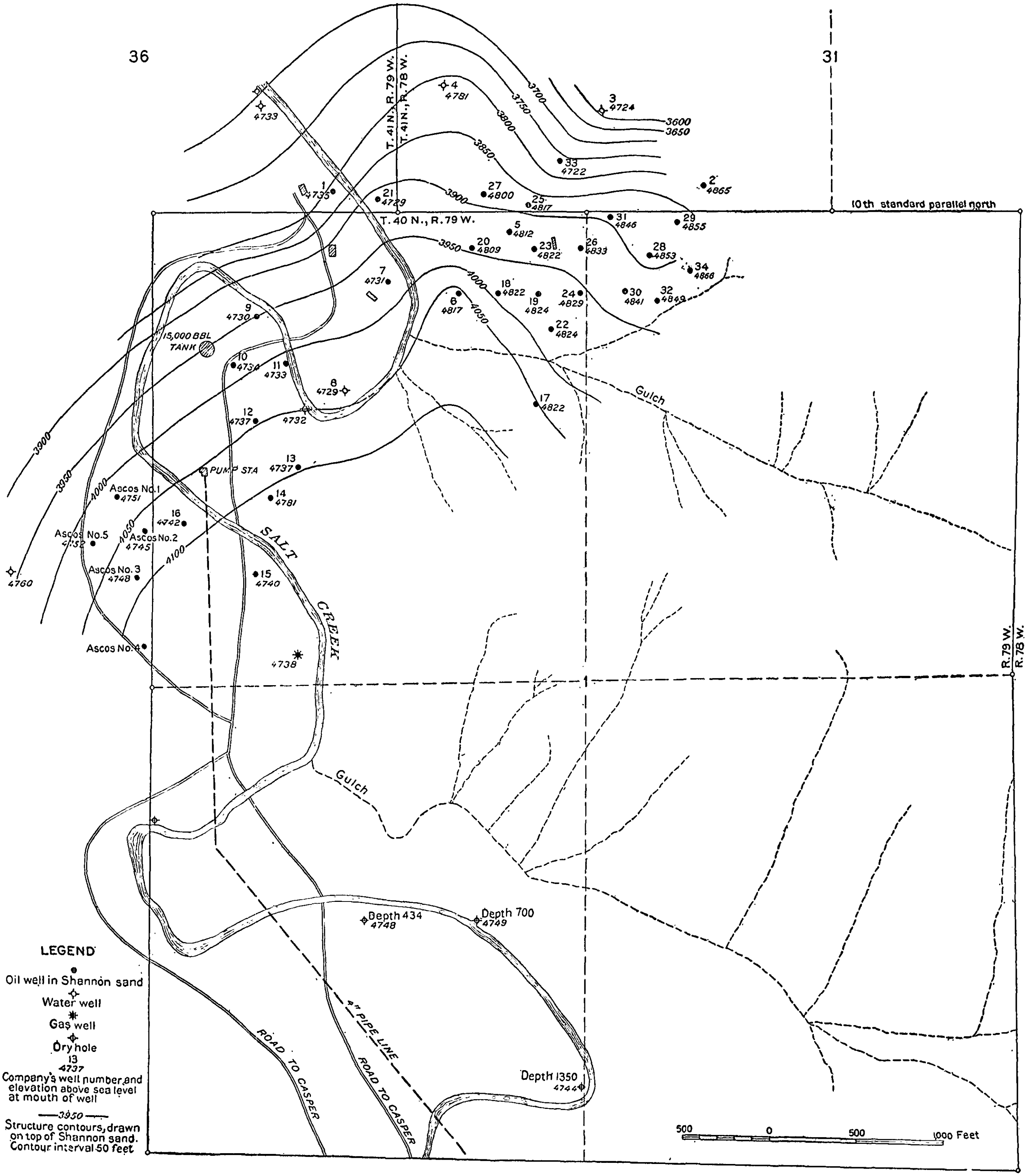
Much of the early history of the Salt Creek field has long been forgotten, and the later history is so involved, because of the number of companies interested and the numerous transfers of lands, that it is somewhat difficult to prepare a clear and concise statement concerning it.

Oil indications were reported from the region before 1880, but the name of the first discoverer of the oil seeps in the field is unknown, and but little notice was taken of the reports of oil in the vicinity until the strike of oil near Lander, on Popo Agie River, awakened general interest in the oil of the State.

Among the early claimants to lands along Salt Creek are mentioned Downey, Sawin, Bothwell, Iba, Schoonmaker, and Hawley.

[1] Wegemann, C. H., The Powder River oil field, Wyo.: U. S. Geol. Survey Bull. 471, pp. 56–75, 1912.

[2] The writer is indebted for most of the information contained in this chapter to Charles W. Burdick, attorney at law, who has made an exhaustive study of the history of the Salt Creek field; N. S. Wilson, manager, Midwest Refining Co.; W. H. Smith and J. W. Van Gordon, former drillers in the Shannon field; and to a report by W. C. Knight, at one time State geologist of Wyoming, on the "Petroleum of Salt Creek, Wyoming" (Univ. Wyoming Petroleum Ser., Bull. 1, June, 1896).



MAP OF THE SHANNON OIL POOL.

Of these claimants Schoonmaker actually obtained patent to the W. ½ secs. 12 and 13, T. 40 N., R. 79 W. His claims were disputed by Iba, and in settlement he deeded to Iba the S. ½ SW. ¼ sec. 13. The first actual drilling in the field was done by P. M. Shannon, president of the Pennsylvania Oil & Gas Co., who became interested in Salt Creek late in the eighties. Shannon acquired the Hawley, Ross, Seymour, and Van Gordon locations, and later those of Dorsett, Straight, Collins, and others. He actually obtained patent only to 160 acres in sec. 1, T. 40 N., R. 79 W., but the locations acquired by him embraced a total of 105,000 acres. The first well was put down in the SE. ¼ SE. ¼ sec. 36, T. 41 N., R. 79 W., in the Shannon pool, and, according to Knight, struck oil late in the fall of 1899, the strike not being made public until the spring of 1890. Three more wells were drilled at Shannon in the next two years. By 1893 rates had been obtained from the railroad and during that year the company pumped 2,300 barrels of 50 gallons each. The oil was hauled to Casper, a distance of 50 miles, by wagons, a load consisting of 45 barrels being pulled by 12 to 18 horses. In 1895 the Pennsylvania Oil & Gas Co. erected a refinery at Casper and put down wells Nos. 5, 6, 7, and 8, W. H. Smith being the driller. In 1901 well No. 9 was completed, and in 1902 wells Nos. 10, 11, 12, and 13. All these wells were small producers, yielding from 4 to 8 barrels of heavy lubricating oil daily. They obtained their supply from the Shannon sand, which lies stratigraphically about 2,000 feet above the Wall Creek or main producing sand of the present Salt Creek field.

During 1895 two other companies entered the field and began drilling. The Wyoming Lubricating Co. put down a well in sec. 31, T. 41 N., R. 78 W., northeast of the Pennsylvania Co.'s camp, which was called Shannon, and the French Syndicate drilled a well on Dugout Creek, about 10 miles southwest, in the SW. ¼ sec. 16, T. 40 N., R. 80 W. Neither of these wells obtained oil.

In 1903 Joseph H. Lobell became interested in the field and soon afterward purchased for foreign investors the Shannon claims (205,000 acres), 160 acres of patented land at Shannon, and the refinery at Casper. In April, 1905, he conveyed all lands acquired from Shannon to the Société Belgo-Américaine des Pétroles du Wyoming, a Wyoming company backed chiefly by Belgian and French capital.. This company granted a lease to another company of foreign investors, which put down the so-called Ascos wells in the NE. ¼ sec. 2, T. 40 N., R. 79 W., southeast of Shannon. These wells were drilled by the Oil Wells Drilling Syndicate, an English corporation at the head of which was Lord Templeton. J. E. Stock was the driller.

The Shannon claims did not cover all the area of the Salt Creek dome, part of which was claimed by Cy Iba, and Lobell subsequently obtained control of the Iba claims, which he transferred early in 1907 to a Holland corporation known as the Petroleum Maatschappij Salt Creek, of Wyoming, and later to a Wyoming corporation of the same name. Lobell retained a directorship in both this company and the Société Belgo-Américaine des Pétroles du Wyoming. Under the terms of the purchase from Lobell, the Petroleum Maatschappij Salt Creek, of Wyoming, acquired claim to 2,200 acres (subsequently increased), which was to be selected by it from an area of 5,200 acres, and Dr. Cesare Porro, an Italian geologist, was sent to this country in May, 1906, to make the selection. It was Dr. Porro who recommended the location, near a large oil seep in the NE. ¼ SE. ¼ sec. 23, T. 40 N., R. 79 W. (about 3 miles south of the Shannon wells), of the first well that reached the producing sand of the present Salt Creek field. Prior to the drilling of this well Stock, as driller for the Oil Wells Drilling Syndicate, had drilled, in October, 1906, a well on Bothwell Draw, in sec. 22, T. 40 N., R. 79 W. This well obtained considerable oil in the shale but did not reach the sand.

The contract for the well in sec. 23 was let by the Petroleum Maatschappij Salt Creek, of Wyoming, to the Belgo-Américaine Drilling Trust, which in turn sublet to the Oil Wells Drilling Syndicate already referred to. It is reported that the contract called for a depth of 3,000 feet if necessary. The syndicate bought a larger rig, retained Stock and his father as drillers, and put S. A. Lane into the field as manager. Drilling began in the fall of 1908 and the oil sand was struck October 21 at a depth of 1,052 feet, oil and gas in small quantities being found near its top. Drilling was continued that night, and at 11 o'clock p. m. the gas took fire from the light of a lantern. J. E. Stock was badly burned and no work was done the following day, but on October 23 drilling was continued to a depth of 24 feet into the sand. Oil rose to the top of the casing and then the well began to flow, throwing a column of oil 100 feet into the air. The flow was periodic, lasting only for a few minutes at a time. The 8¼-inch casing was capped, but the force of the accumulated gas twice blew off the cap. The third attempt to shut in the well was successful.

The Stock Oil Co. was formed in 1907, being composed of J. E. Stock, his father, and S. A. Lane. It drilled one well which obtained oil in shale, and for this obtained patent to the E. ½ sec. 25, T. 40 N., R. 79 W.

The validity of the claims belonging to the Petroleum Maatschappij Salt Creek was questioned on several grounds. In 1908 Hegens, Clarkson, Palmer, and others made locations covering these contested lands and conveyed their locations to the Central Wyoming Oil & Development Co., which later made a lease to the Petroleum Maatschappij Salt Creek Co.

All Government land in the Salt Creek field was withdrawn from entry September 27, 1909,[1] and after examination part of the area withdrawn was restored June 25, 1910, the Government holding as withdrawn from entry all lands considered valuable for oil in the Salt Creek and Teapot domes.

Late in the fall of 1909 the Petroleum Maatschappij Salt Creek is reported to have drilled, under the direction of Conrad Herbert, five shallow wells, which encountered oil in the shale, and the following year to have drilled 17 wells which reached the Wall Creek sand.

Late in 1909 and early in 1910 Fitzhugh & Henshaw, of California, located claims covering the whole field on the ground that many of the former claims were, for one reason or another, invalid.

The Reed Investment Co., of Denver, entered the field in 1910, first leasing and buying lands in secs. 11 and 14, T. 39 N., R. 79 W., and afterward purchasing the Henshaw interests. In May, 1911, it organized a separate company, known as the Midwest Oil Co., to operate in the field. This company entered into a contract with Fitzhugh to produce oil from his lands on a royalty.

Late in 1911 the Wyoming Oilfields Co. took over the holdings of the Petroleum Maatschappij Salt Creek and the Société Belgo-Américaine des Pétroles du Wyoming and entered into a contract with the Natrona Pipe Line & Refinery Co., organized earlier in 1911. The company built a refinery in Casper and a 6-inch pipe line to the field. In June, 1911, the Midwest Oil Co. built a refinery at Casper and in the same year a pipe line to the field. The pipe line was in operation in November, 1911, and the refinery in February, 1912. In 1912 the Franco Petroleum Co. was organized to lease the interests of the Wyoming Oilfields Co. and the Natrona Pipe Line & Refinery Co. and afterward sold the leases to the Midwest Refining Co., organized in January, 1914. This company also took over the Midwest refinery, the pipe lines, and other property.

On April 30, 1915, by presidential order, certain lands on the Teapot domes were set aside for the use of the Navy as Petroleum Reserve No. 3.

At present (April, 1917) the Salt Creek field is producing about 10,000 barrels of oil a day and the Midwest Refining Co. is operating a large refinery at Casper. The Standard Oil Co. has installed a cracking plant near the Midwest refinery and buys certain of the products, which are reworked under the cracking process to produce a higher percentage of gasoline.

[1] The validity of the withdrawal was upheld by the Supreme Court of the United States in its decision handed down Feb. 23, 1915, in the case of the United States *v.* Midwest Oil Co., 236 U. S., 459. See Ball, M. W., Petroleum withdrawals and restorations affecting the public domain: U. S. Geol. Survey Bull. 623, p. 24, 1916.

TOPOGRAPHY.

RELIEF.

The surface of the country in the vicinity of the Salt Creek field is rough though by no means mountainous. Along Salt Creek itself and some of its tributaries, such as Castle Creek, there are broad flats, but the land back from these major streams is cut by a network of deep gulches into the type of topography known throughout the West as badlands.

The shape of the hills differs in different parts of the field, being influenced largely by the character of the underlying rock. Shale develops smooth rounded slopes, whereas sandstone forms rugged escarpments that may be traced for miles. As the courses of these escarpments are dependent on the direction of dip of the rocks about the fold that forms the oil field, they indicate the shape and the position of the fold. One bed, the Shannon sandstone, which originally extended in a broad arch over the fold, has been in part removed by erosion, and its truncated edges now stand in an escarpment that completely encircles the Salt Creek dome. It also forms the northward-trending ridge about 3 miles to the west. At the north end of the dome the sandstone is less conspicuous as a cliff-maker, but toward the south it rises in sheer cliffs that are in some places 100 feet or more in height. Salt Creek, which has worked rapidly in the soft shale that lies below the sandstone, has excavated a system of valleys on the high part of the anticline, so that the present relief is the reverse of that produced by the folding of the rocks, the surface on the anticline being lower than that in the adjoining synclines.

Two other sandstone beds form prominent escarpments in the vicinity of the field. One of these beds, which forms the lower part of the Parkman sandstone member, lies about 1,300 feet above the Shannon sandstone. Its outcrop partly encircles the dome on the east lying outside of that of the Shannon sandstone. Erosion has carved the massive Parkman sandstone into many strange and picturesque forms. Isolated masses rise here and there like towers above the general level, and where the entire thickness of the sandstone is exposed it stands in cliffs that may be seen for many miles.

Outside the escarpment of the Parkman sandstone is a ridge formed by a third sandstone bed. This ridge, although it is at many places inconspicuous, is easily recognized by the pine trees that it almost invariably carries. In the writer's first report on the field it was termed "Little Pine Ridge," and the sandstone composing it has since been referred to as the Teapot sandstone.[1] That name will be adopted in the present report.

[1] Hares, C. J., Anticlines in central Wyoming: U. S. Geol. Survey Bull. 641, pp. 233–279, 1916.

Two other sandstones form local ridges. One of these, which lies between the Shannon sandstone and the Parkman sandstone, forms a ridge about 4 miles long in the northwest quarter of T. 40 N., R. 78 W., and the northeast quarter of T. 40 N., R. 79 W. This sandstone is present also in the syncline west of the Salt Creek dome and on the Teapot dome, to the northeast. The second sandstone, which lies about 325 feet above the Teapot sandstone, can be traced throughout the field, and in several places it forms prominent escarpments.

DRAINAGE.

Salt Creek, the principal stream in the field, rises about 20 miles southeast of the town of Salt Creek and flows in a general direction N. 30° W. to join Powder River in the SE. ¼ sec. 15, T. 43 N., R. 79 W., near the Davis ranch. Its total length is about 50 miles. During the summer the creek flows only in rainy weather, the water ordinarily standing in pools along a dry bed. It is therefore mapped as an intermittent stream, but it is rather large and after heavy storms it becomes a dangerous and sometimes impassable river.

It enters the area shown on the accompanying map at the southeast corner of T. 39 N., R. 78 W., and in less than 2 miles crosses the escarpment of the Parkman sandstone, which rims the Teapot anticline. In sec. 16, near the middle of the township, it is joined from the south by Teapot Creek, whose branch, Little Teapot, drains the Teapot anticline. From sec. 16 it flows northward for about 5 miles in a valley that lies between the Parkman escarpment, on the east, and the escarpment or rim rock of the Shannon sandstone, on the west, and in sec. 29, T. 40 N., R. 78 W., it turns abruptly to the west and cuts through the Shannon rim rock. Inside the rim rock of the Salt Creek dome the stream is joined, in sec. 25, T. 40 N., R. 79 W., by another stream from the south, known as Castle Creek, which drains the south half of the dome within the Shannon rim and the syncline southwest of it.

From sec. 25, T. 40 N., R. 79 W., Salt Creek flows due north for 7 miles, recrossing the Shannon rim rock at the north end of its outcrop and passing through the old camp of Shannon. After recrossing the Parkman escarpment a mile north of Shannon it flows northwestward to Powder River.

WATER SUPPLY.

The surface water in the field and that obtained by drilling is all more or less alkaline. The water in Salt Creek, when that stream is flowing, can be used, but is not very palatable. The water in Castle Creek is so highly charged with salts during dry weather that it is hardly fit even for the use of stock.

The Midwest Oil Co. has drilled six wells in sec. 34, T. 40 N., R. 79 W., to obtain a supply of water for the town of Salt Creek. These wells obtain from the Shannon sand a mineralized water which is pumped into a storage tank and conveyed through a pipe line to the town, where it is distilled for general use.

GEOLOGY.

STRATIGRAPHY.[1]

ROCKS DESCRIBED.

The rocks from which oil is obtained in the Salt Creek field belong to the Upper Cretaceous series (see accompanying table), but in a discussion of the geology of oil accumulation in the region it is necessary to consider the rock formations down to the Jurassic, and as Tertiary strata crop out near the field they also will be briefly described.

Most of the older rocks do not crop out on the Salt Creek anticline but are exposed in the fold known as the Powder River dome,[2] which lies 15 miles west of Salt Creek. In this dome oil seeps are found in the Sundance, Morrison, and Cloverly, and in the Mowry member of the Benton shale. The oil at Salt Creek occurs at higher horizons in the Benton and the Montana group, but as the older rocks just mentioned all doubtless underlie the Salt Creek dome it is apparent that a study of oil accumulation in that dome involves all the rocks from the Sundance to the Montana group.

[1] Some of the geologic names employed in the following discussion are not the same as those used by the writer in his former report on the field (U. S. Geol. Survey Bull. 452). It often happens that the same formation is studied by different men in two or more widely separated areas, and until work is done in the intervening country it is impossible to prove that the beds studied are of the same age and should be assigned to the same formation. Even if the beds appear to be equivalent it is desirable to avoid possible error that may be occasioned by the use of one name for rocks that may not prove to be equivalent, so that different names are at first applied to the beds in the two areas. As soon as the equivalency of the beds studied in the two areas can be established one name is adopted for them, and this necessitates a change of the name used for the beds in one of the areas. Such changes cause confusion at first, but they eventually lead to clearness, for the same name should be used for a single formation that covers broad regions.

[2] Wegemann, C. H., The Powder River oil field, Wyo.: U. S. Geol. Survey Bull. 471, pp. 56–75, 1912.

Rock formations in Salt Creek oil field, Wyo.

System.	Series.	Group.	Formations and members as classified in the writer's former report on the field.	Formations and members recognized in this report.	Character.	Thickness in feet.
Tertiary.	Eocene.		Fort Union formation.	Wasatch formation.	Yellow sandstone, gray shale and coal.	2,400
				Fort Union formation.	Fine-grained bluish-white sandstone and gray shale.	2,000
Tertiary(?)	(?)		Lance formation.	Lance formation.	Concretionary buff sandstone and shale bearing *Triceratops* remains.	3,200
Cretaceous.	Upper Cretaceous.	Montana.	Fox Hills sandstone.	Lewis shale with thick sandstone at top and another sandstone in middle.	Sandstone, white to brown, and gray shale.	1,400
			Pierre formation. Parkman sandstone member.	Mesaverde formation, including Parkman and Teapot sandstone members.	Shale, sandstone, thin coal beds.	845
			Pierre formation. Shannon sandstone lentil.	Steele shale, including Shannon sandstone member.	Buff sandstone and gray shale.	2,275
		Colorado.	Niobrara shale.	Niobrara shale.	Light-colored shale, in parts somewhat arenaceous.	735
			Benton shale.	Benton shale.	Dark shale.	220
			Benton shale. Wall Creek sandstone lentil.	Benton shale. Wall Creek sandstone member and lower sands with interbedded shale.	Buff to white sandstone and gray shale.	685
			Benton shale.	Benton shale.	Dark shale.	250
			Benton shale. Mowry shale member.	Benton shale. Mowry shale member.	Firm slaty shale, usually forming escarpment. Weathers light gray and bears numerous fish scales.	280
			Benton shale.	Benton shale.	Dark shale.	205
	Lower Cretaceous.		Benton shale.	Cloverly formation.	Thin sandstone and dark shale.	150
			Dakota (?) sandstone.		Conglomerate.	
Cretaceous (?)	(?)		Morrison formation.	Morrison formation.	Variegated shale with several sandstone beds.	250
Jurassic.	Upper Jurassic.			Sundance formation.	Shale, limestone, and sandstone.	150

JURASSIC SYSTEM.

SUNDANCE FORMATION.

The Sundance formation is of marine origin. It is exposed in the Powder River field at only one locality—in sec. 33, T. 41 N., R. 81 W., along the bed of a canyon that enters Salt Canyon from the north. Here about 10 or 15 feet of the formation is brought to the surface by a sharp minor fold. The exposure shows several beds of argillaceous fossil-bearing limestone a foot or two thick, and numerous intervening beds of dark-gray shale. At the top is an 8-foot bed of shale that contains fossils in its lower part but none in its upper 3 or 4 feet. This bed probably represents a transition from the Sundance below to the Morrison above. The Sundance as exposed along the Big Horn uplift to the northwest is about 150 feet thick and is underlain by Triassic and Permian red beds known as the Chugwater formation. In the Powder River field oil is found in the Sundance, in small quantities at least, as is shown by an oil seep in the SW. ¼ sec. 33, T. 41 N., R. 81 W., along the sharp minor fold mentioned above.

The following fossils were collected in the SW. ¼ sec. 33, T. 41 N., R. 81 W., and were identified by T. W. Stanton:

Pentacrinus asteriscus Meek and Hayden.
Ostrea strigilecula White.
Ostrea engelmanni Meek.
Camptonectes bellistriatus Meek.
Pleuromya subcompressa (Meek).
Dentalium subquadratum Meek.
Belemnites densus Meek and Hayden.

CRETACEOUS (?) SYSTEM.

MORRISON FORMATION.

The Morrison formation, which is doubtfully referred to the Cretaceous, overlies the Sundance in apparent conformity. It is, however, a fresh-water deposit, whereas the Sundance is marine. The Morrison is 250 feet thick and consists of shale and four or five hard, thin interbedded sandstone strata. In outcrop these sandstone beds form conspicuous ledges. The shale in the lower part of the formation is greenish; that in the upper part is maroon, but the colors are by no means pronounced, and the term "variegated" has been well applied to them. In the Powder River field oil seeps occur in at least two of the sandstone beds.

Dinosaur remains have been found in the Morrison formation along the Big Horn uplift. The only fossil observed in the Powder River field was the fresh-water shell *Unio felchii*, which occurs in considerable numbers in the NE. ¼ sec. 33, T. 41 N., R. 81 W., in a sandstone near the base of the formation.

CRETACEOUS SYSTEM.

LOWER CRETACEOUS SERIES.

CLOVERLY FORMATION.[1]

Upon the Morrison lies a conglomerate[2] containing some layers of sandstone (Pl. IV, *B*), the whole 56 feet thick, and including at the base a thin bed of coal, which in many localities suffered erosion before the conglomerate was laid down, as is shown by the bits of coal that occur throughout the bed. There is much cross-bedding in the conglomerate. In the Powder River field the sandstone is a lithologic unit, but 25 miles to the north, where it crops out along the Big Horn uplift, it consists of numerous thin layers of sandstone and conglomerate interbedded with shale, some of it pink and not very different in appearance from the underlying Morrison. In this region fossil plants were collected from layers of shale that lay between beds of conglomerate near the base. These fossils have been identified by F. H. Knowlton as

Podozamites lanceolatus (Lindley and Hutton) Schimper.
Oleandra graminaefolia Knowlton?
Cladophlebis sp.
Pterophyllum montanense (Fontaine) Knowlton.

According to Mr. Knowlton these are undoubtedly Kootenai species. There appears to be little question, therefore, that the conglomerate is equivalent in age to at least part of the Kootenai of Montana,[3] probably being the same as the Pryor conglomerate of the Elk Basin oil field.[4] The conglomerate, so far as known, is the principal oil-bearing formation of the Powder River field. It is from this conglomerate that the oil obtained in the open wells of Trail Canyon and Oil Canyon is derived, and in it most of the oil seeps occur. The area in which the conglomerate yields oil is, however, small, and the Powder River field is not yet commercially productive.

Overlying the conglomerate is 80 feet of dark unfossiliferous shale, above which is a 14-foot bed of shaly sandstone, the top layers of which are strongly ripple marked. This bed, though it is comparatively thin, is found at many places throughout this region and appears to be of wide extent.

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[1] Darton, N. H., Geology of the Bighorn Mountains: U. S. Geol. Survey Prof. Paper 51, p. 50, 1906.

[2] This conglomerate was referred to as Dakota (?) in the writer's former report (U. S. Geol. Survey Bull. 452).

[3] Fisher, C. A., Southern extension of the Kootenai and Montana coal-bearing formations of northern Montana: Econ. Geology, vol. 3, pp. 77–99, 1908.

[4] Hares, C. J., unpublished report.

The age of the rocks described above, which are grouped under the name Cloverly formation, is in doubt. In the Black Hills Darton[1] found a Lower Cretaceous sandstone, which he called the Lakota, that would appear to be the equivalent, in part at least, of the conglomerate described above. This sandstone is overlain by the Fuson shale, which also is of Lower Cretaceous age and which underlies the true Dakota sandstone, of Upper Cretaceous age. If the formations of the Black Hills are all represented in the Salt Creek region the thin bed of sandstone that lies 80 feet above the top of the conglomerate may represent the true Dakota, and the shale overlying the conglomerate may be the equivalent of the Fuson shale, of Lower Cretaceous age. On the other hand, the conglomerate may represent the top of the Lower Cretaceous in this area and all the rocks above it may belong to the Benton. As the beds are practically barren of fossils it has not yet been possible to determine their geologic age.

UPPER CRETACEOUS SERIES.

COLORADO GROUP.

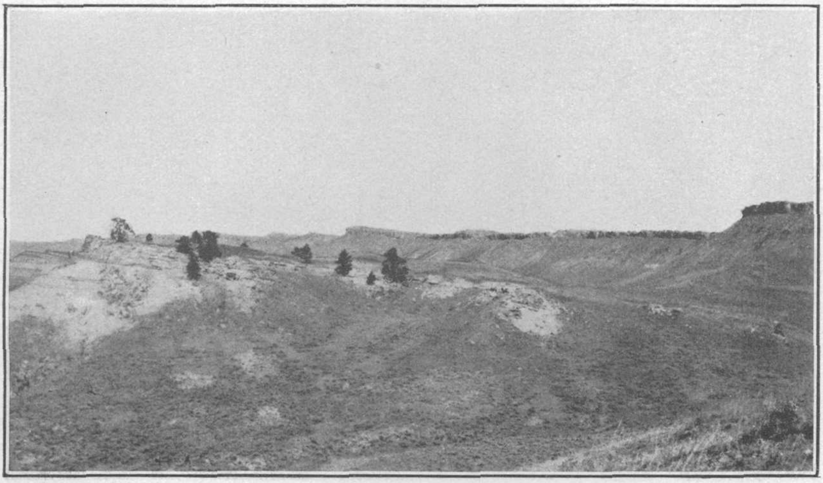
BENTON SHALE.

Above the thin bed of sandstone which, as explained, may be the equivalent of the Dakota, lies 175 feet of dark shale near the base of which shark teeth have been found. At its top, underlying the well-known fish-scale shale of the Mowry member, described below, is a bed of white sandstone of variable thickness, at the base of which is much petrified wood. At one locality a thin bed of very light weight subbituminous coal was observed at this horizon. The sandstone is not more than 6 or 8 feet thick in the Powder River field, but at many places it forms a conspicuous white ledge. Farther north, along the foot of the mountains, the same bed is exposed and attains considerably greater thickness.

Above the sandstone bed is 20 feet of dark shale, overlying which is a light-gray cliff-forming shale of marine origin, which contains immense numbers of fish scales ranging in diameter from one-eighth to three-eighths of an inch. This shale forms a lithologic unit that extends over many thousand square miles and is known as the Mowry shale member of the Benton shale. In its lower part there are several beds of bentonite,[2] a hydrous silicate of alumina, and at its top a bed of the same material, 5 or 6 feet thick. The upper bed of bentonite makes a conspicuous white band along the foot of the dip slope that is at many places formed by the Mowry member and is

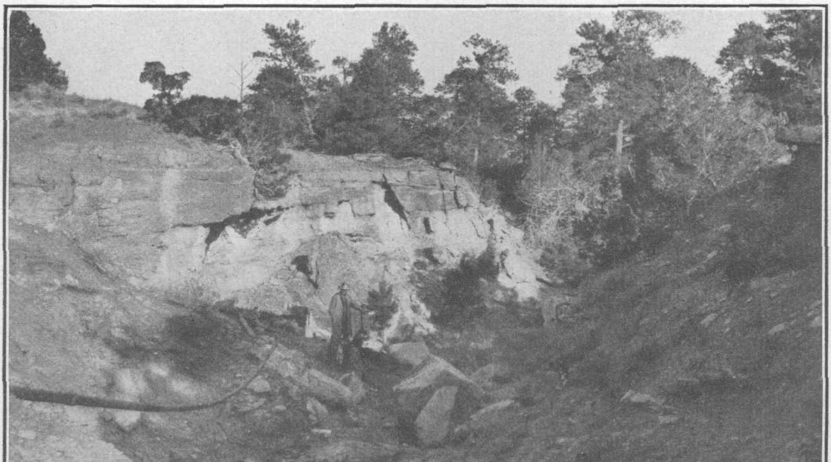
[1] Darton, N. H., Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming: U. S. Geol. Survey Prof. Paper 65, 1909.

[2] D. F. Hewett (unpublished observations) regards it as an altered volcanic ash.



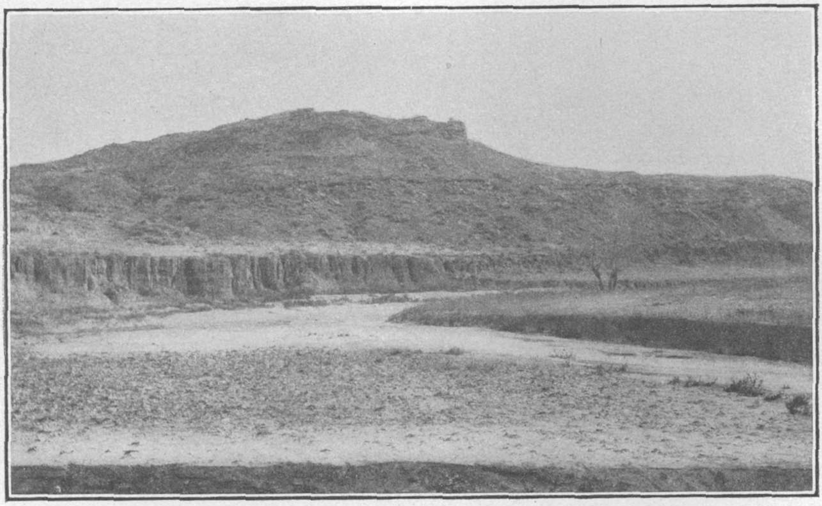
A. ESCARPMENT OF WALL CREEK SANDSTONE MEMBER (AT RIGHT).

Sandstone bearing pines is 220 feet below.



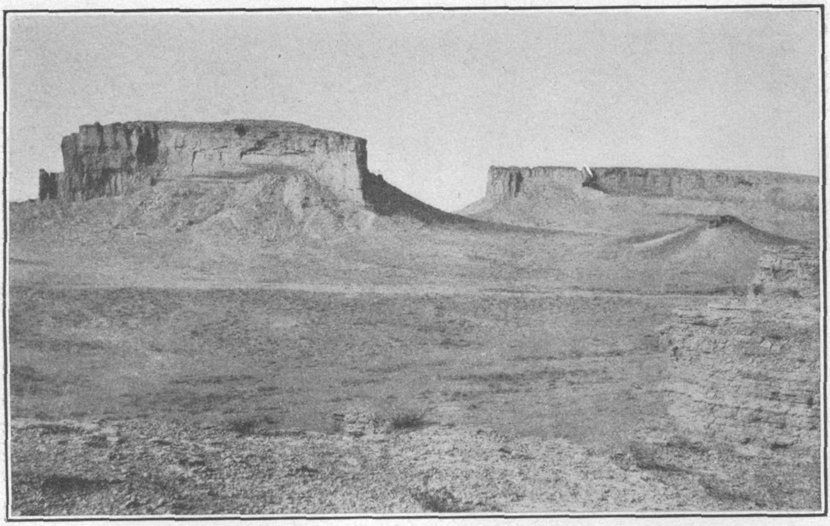
B. SANDSTONE OF THE CLOVERLY FORMATION AND OPEN OIL WELL, POWDER RIVER OIL FIELD, 18 MILES WEST OF SALT CREEK.

Iron pipe on left leads from the well.



A. SHANNON SANDSTONE MEMBER 1½ MILES SOUTH OF SHANNON.

Both ledges appear—the upper at the crest of the hill, the lower, which carries the oil, halfway down the slope. The cut bank above the creek is alluvium.



B. CASTLE ROCK, SHANNON SANDSTONE MEMBER, SW. ¼ SEC. 8, T. 39 N., R. 78 W.

The two ledges here stand in a single cliff.

easily recognized, especially after rain, when it is exceedingly slippery. The Mowry in this field is about 280 feet thick.

Most of the fish scales found in the Mowry appear to have been derived from one species of fish, which must have been exceedingly numerous in the ocean in which the shale was put down. In some parts of the Mowry every splinter of the shale contains one or more of the scales.

Above the band of bentonite at the top of the Mowry is 250 feet of very dark shale, which contains, near its middle, numerous thin beds of ferruginous limy shale only an inch or two thick. These weather to a deep reddish brown.[1]

Above the dark shale is a group of beds of sandstone and shale, in all 685 feet thick, which represents, at least in part, the Frontier formation of southwestern Wyoming. The highest member of this group is the Wall Creek sandstone (Pl. IV, *A*), which is the principal oil-bearing sand in the Salt Creek field. The possibility of finding oil in some of the sandstone beds below the Wall Creek in that field must be considered,[2] and therefore all the sands are worthy of detailed description. The lowest, which lies immediately above the dark shale just described, consists of medium-grained dirty-white sandstone and is from 30 to 40 feet thick. At many places it carries a growth of pine trees. Above it is 35 feet of gray shale, which is overlain by 25 feet of shaly sandstone, also carrying a growth of pine. Above this sandstone is 150 feet of gray shale, and above this is a bed of sandstone that is the most promising oil reservoir found below the Wall Creek. This sandstone is usually referred to as the "Lower Wall Creek sandstone." It is not over 20 or 25 feet thick in its massive part, although sandy shale above and below it may carry oil. It is the highest bed that carries pine trees, and is a massive, medium-grained sandstone, with a calcareous cement, and would apparently form a good reservoir for oil. The sand grains composing the rock are colorless quartz, but the sandstone as a whole has a bluish-white cast, due to the presence among the quartz grains of innumerable black particles, which were apparently derived from the same rock that furnished the numerous well-rounded dark quartzitic pebbles that are distributed sparsely through the mass of sandstone. On top of the sandstone is a 6-inch bed of conglomerate formed of these same rounded black pebbles, which range in diameter from an eighth of an inch to an inch. Among them are found here and there a few pebbles of transparent quartz. It is interesting to note that thin

[1] The rocks of the Benton from its base up to the top of these dark shales have been called in some other regions the Graneros shale. See Darton, N. H., Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming: U. S. Geol. Survey Prof. Paper 65, 1909. Hares, C. J., unpublished notes.

[2] Since the above was written oil in commercial quantity has been struck in the Lower Wall Creek sand in the Hjorth well, in sec. 32, T. 40 N., R. 79 W.

beds of conglomerate composed of similar black pebbles have been reported at about this horizon from the Big Horn Basin.[1] Overlying this bed of conglomerate in the Powder River field is a bed of bentonite about 12 inches thick. Above the bentonite bed is 110 feet of shale, which is overlain by 20 feet of shaly sandstone; above this are 20 feet of shale, 10 feet of sandstone, 65 feet of shale, 15 feet of sandstone and shale, and 20 feet of shale, which immediately underlies the Wall Creek sandstone member. The Wall Creek as reported in wells in the Salt Creek field is about 125 feet in thickness, but as exposed along the east flank of the Powder River dome it appears to be about 100 feet thick. The upper surface of the bed forms a dip slope almost a mile long, and a certain part of it may have been removed by erosion so that the true thickness of the bed may be that recorded in the wells, for because of the peculiar nature of the exposure it is impossible to make an accurate measurement of the bed at the surface. The Wall Creek sandstone is shaly at its base, the shale occurring as thin lenses interbedded with the sand. About 40 feet above the base is a 10-foot bed of shale, which divides the sandstone into two parts. In color the sandstone is dirty buff. It is medium grained and in many places cross-bedded. It contains fragments of petrified wood, shark teeth an inch and a half long, and numerous shells of invertebrates, which, although marine, probably lived not far from shore. In the shale at the base of the Wall Creek is found the large coiled ammonite, *Prionocyclus wyomingensis* Meek, which is from 12 to 18 inches in diameter, and also the following salt-water forms:

Inoceramus fragilis Hall and Meek?
Scaphites sp.
Metoicoceras.
Inoceramus labiatus Schlotheim.
Pachydiscus? sp.
Scaphites ventricosus Meek and Hayden?

If the fossils are to be relied upon the Wall Creek sandstone, although it is the highest sandstone bed in the Benton, does not mark the top of that formation. It is overlain by 220 feet of shale, which is somewhat darker than that below it and contains four thin beds of ferruginous limestone at intervals of 50 or 60 feet. The highest of these calcareous beds may be considered as marking the top of the Benton shale.[2] The fossils collected at this horizon are as follows:

[1] Hewett, D. F., The Shoshone River section, Wyoming: U. S. Geol. Survey Bull. 541, pp. 89–113 (especially p. 98), 1914.

[2] The shale between the top of the Wall Creek and the base of the Niobrara is called by some authors the Carlile shale. See Darton, N. H., Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming: U. S. Geol. Survey Prof. Paper 65, 1909.

Ostrea sp., possibly O. congesta Conrad.
Inoceramus sp. related to I. deformis Meek.
Tapes? sp.
Turritella sp.
Volutoderma? sp.
Scaphites ventricosus Meek and Hayden.
Exogyra sp.
Avicula sp.
Inoceramus fragilis Hall and Meek.
Fusus? sp.

NIOBRARA SHALE.

About 220 feet above the top of the Wall Creek sandstone the dark shale of the Benton gives place to the buff or bluish-gray shale of the Niobrara, a shale that contains fragments of very thick shelled *Inoceramus*, to which are attached in clusters numerous shells of *Ostrea congesta.* The association of these two fossils is said by T. W. Stanton to be typical of this formation. The Niobrara shale lies unexposed in a broad valley, so that the vertical limits of the formation are somewhat difficult to trace. The lower limit, as already stated, is placed 220 feet above the top of the Wall Creek sandstone, at a horizon where the shale abruptly changes from a dark to a light color and becomes somewhat sandy. At this horizon also *Ostrea congesta* appears in considerable numbers; below it only isolated specimens can be found.

At the top of the Niobrara formation are two or three beds of limestone only a few inches in thickness. *Ostrea congesta* is fairly abundant in the shale below these beds, but none occur in the shale above them, which contains many large *Baculites*, distinctive of the Montana group. At the limestone horizon, also, the lithologic character of the shale changes slightly; above the limestones there are numerous very thin beds of splintery calcareous shale which weathers red, and cone in cone structure is abundant, whereas below them neither occurs. In the Montana group alkali is apparently more abundant than in the Niobrara shale, a fact indicated by the white coating deposited by evaporation. Where fossils can not be found, these differences, though perhaps unimportant in themselves, furnish convenient criteria for separating the Niobrara from the overlying Montana.

Owing to the lack of exposures the thickness of the Niobrara shale is difficult to determine. Three sections made along the outcrop near the town of Kaycee, about 20 miles northwest of Salt Creek, give an average of 735 feet. Another section measured on the southeast side of the Powder River dome, about 4 miles southwest of Scott's ranch, gives a thickness of 1,025 feet, which is unusually great. The exposures in this locality are good, and there seems to be little chance of error unless concealed faults have duplicated the beds. Even if this section is disregarded, however, it is evident that the Niobrara is of unusually great thickness in this general region, as compared with others, although it is much less distinct in lithologic character.

MONTANA GROUP.

STEELE SHALE.

Above the Niobrara the gray shale of the Steele[1] (Pl. VII, *A*) extends uninterruptedly for 1,045 feet, constituting the surface rock within the rim of the Salt Creek dome and forming the hills usually called adobe. As stated above, the shale contains numerous beds, a quarter of an inch to half an inch thick, of firmer calcareous shale that contains iron and that turns red on exposure. In T. 40 N., R. 79 W., a peculiar conglomerate occurs about 400 or 500 feet above the base of the Steele in a bed 2 feet thick. The matrix and some of the pebbles of this conglomerate are red, but it contains also a few black, well-rounded pebbles and numerous fish teeth. The bed extends for only a mile along its outcrop north and south, being apparently replaced by shale. In sec. 14, T. 40 N., R. 79 W., is a thin red sandstone that appears to lie at about the same horizon as the fish-tooth conglomerate, although its outcrop does not connect with it. The bed contains dark pebbles, and on its surface was found a bone of a swimming saurian. A water sand is reported at this horizon in one of the Shannon wells. The principal fossils in this part of the Steele are *Baculites*, but even these are not numerous.

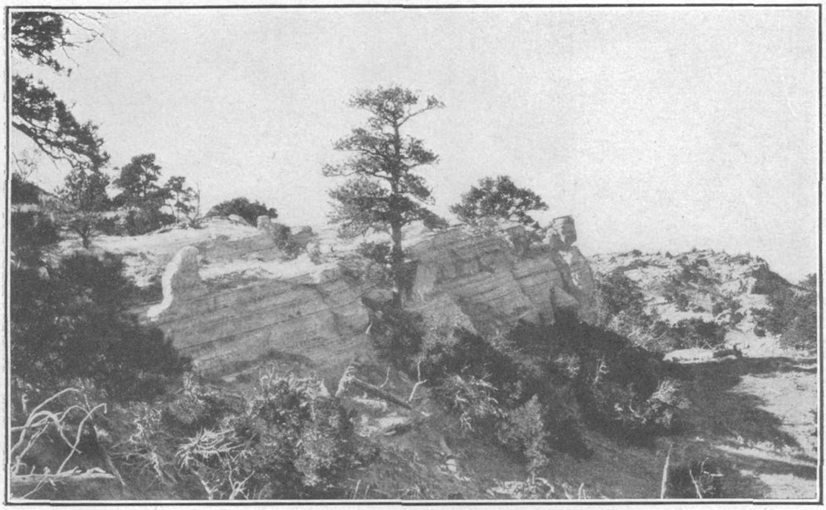
Upon the shale just described lies the Shannon sandstone member (Pl. V), which forms the rim rock of the Salt Creek dome and which has a thickness of 130 feet. It is somewhat variable in character but generally contains two resistant beds and an intermediate mass of softer sandstone or shale. From it is obtained the heavy lubricating oil of the Shannon field. The bed is further described on page 33.

Above the Shannon sandstone is 1,100 feet of shale, with a 30-foot bed of sandstone, in many places inconspicuous, 400 feet above its base. This bed is the water sand that is reported in many of the Shannon wells. About 100 feet below the top of the shale are definite marine Montana invertebrates. Here also was found a vertebral centrum of a marine reptile that was doubtfully determined as *Mosasaurus*.

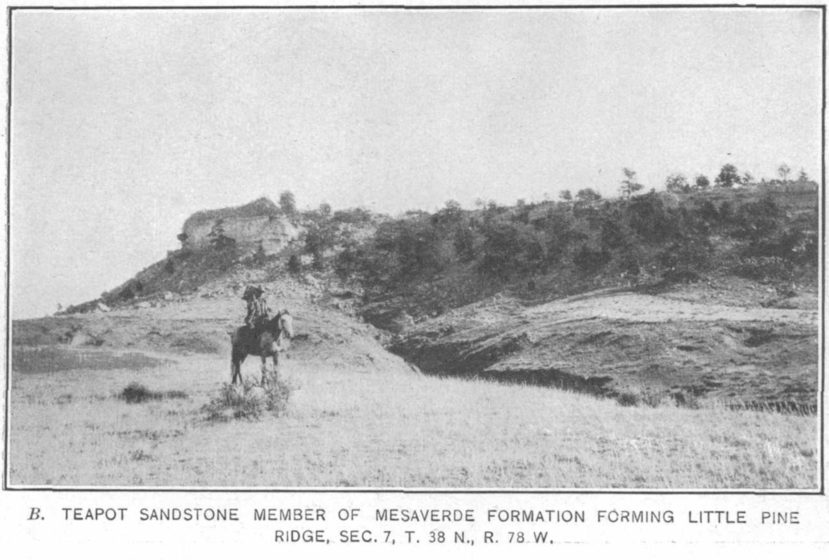
MESAVERDE FORMATION.

Above the shale just described lies a series of beds of sandstone, coal, and shale, about 845 feet thick, which represents in whole or

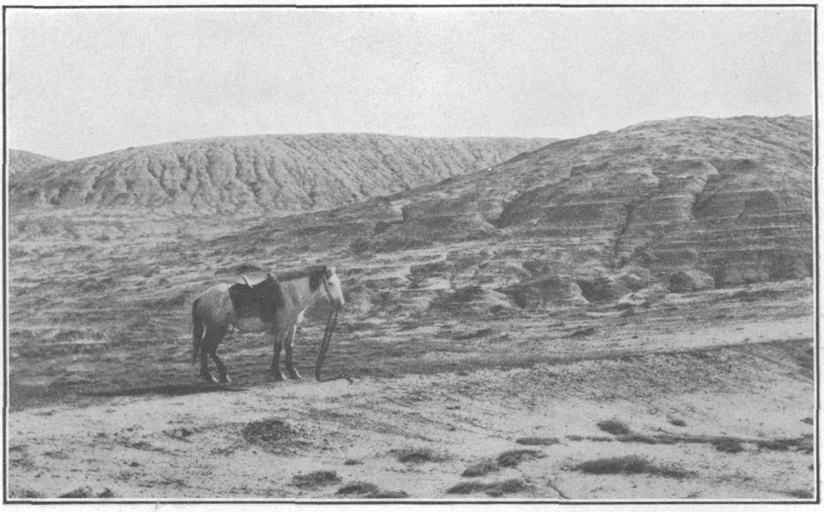
[1] The Steele shale is the equivalent of the lower part of the Pierre as defined in the writer's former report on the field.



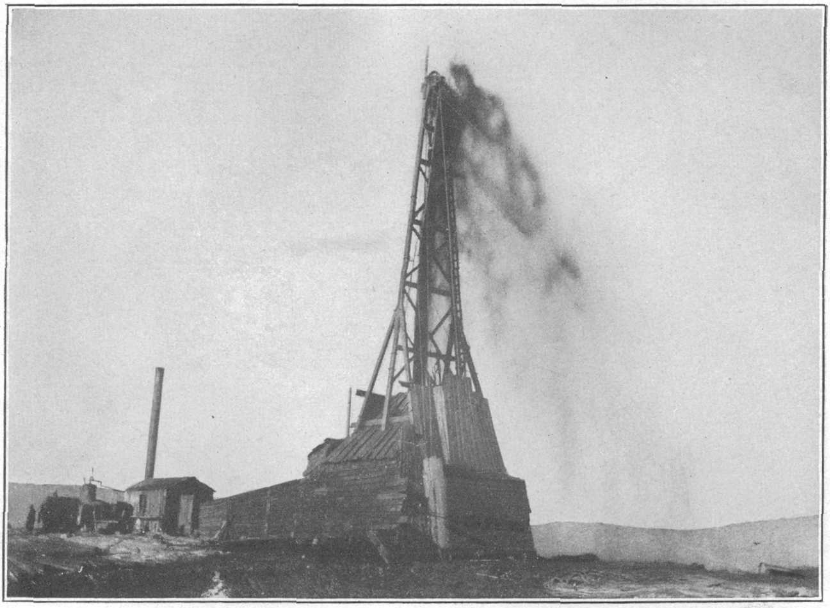
A. MASSIVE SANDSTONE AT BASE OF PARKMAN SANDSTONE MEMBER OF MESAVERDE FORMATION, SEC. 4, T. 38 N., R. 78 W.



B. TEAPOT SANDSTONE MEMBER OF MESAVERDE FORMATION FORMING LITTLE PINE RIDGE, SEC. 7, T. 38 N., R. 78 W.



A. STEELE SHALE IN THE SALT CREEK ANTICLINE, SEC. 35, T. 40 N., R. 79 W.



B. FLOW OF OIL AT DUTCH WELL NO. 1, DECEMBER, 1908, BEFORE WELL WAS CAPPED.

in part the Mesaverde formation of Colorado and southern Wyoming and to which that name is here applied.

The Mesaverde may be divided into three members—the Parkman sandstone at the base, the Teapot sandstone at the top, and an intervening unnamed member of sandstone and shale.

Parkman sandstone member.—The Parkman sandstone member is about 470 feet thick. It consists of a basal sandstone (170 feet), a capping sandstone (110 feet), and an intervening series (190 feet) of shale, carbonaceous shale, and coal beds. The name was given by Darton[1] to equivalent rocks that form a pronounced ridge or escarpment along the Big Horn Mountains. In the Salt Creek field the basal sandstone (Pl. VI, *A*) forms an escarpment wherever it is exposed. It is a very fine grained buff sandstone and shows much cross-bedding.

Almost at the base of this massive sandstone near Shannon the following fossils were found:

- Avicula nebrascana Ellis and Shumard.
- Cardium speciosum Meek and Hayden.
- Tellina? sp.
- Leptosolen sp.
- Corbulamella gregaria Meek and Hayden.
- Liopistha undata Meek and Hayden.
- Inoceramus crippsi var. barabini Morton.
- Sphaeriola sp.
- Mactra formosa Meek and Hayden.
- Lunatia sp.

The bones of a large dinosaur have also been found in the sandstone. The writer measured one which was 6 inches in diameter and 2 feet 6 inches long in its exposed portion. The entire bone was considerably longer. It was identified by C. W. Gilmore as the distal half of a femur of an animal belonging to the genus *Trachodon.* Turtle shell was associated with it, and petrified wood is common in the sandstone.

A group of thin coal beds, dark shale, and white sandstone, the whole 190 feet thick, increases the height of the sandstone escarpment or forms a second escarpment outside of it. These beds apparently represent alternating brackish-water and fresh-water conditions. Some of the strata contain considerable iron, which gives them a brownish cast. The contrast in colors—white, black, brown, and gray—between the numerous thin beds of this group is striking. The coal beds are less than 14 inches thick in this field. They occur at the same horizon as those mined 50 miles farther south, near Casper ("coal B" of Shaw).[2]

[1] Darton, N. H., Geology of the Bighorn Mountains: U. S. Geol. Survey Prof. Paper 51, 1906.

[2] Shaw, E. W., The Glenrock coal field, Wyo.: U. S. Geol. Survey Bull. 341, map opp. p. 154, 1909.

Capping the shale and coal series is a white sandstone 110 feet thick, and above it in certain localities is a thin calcareous layer in which are embedded fragments of dinosaur bones, among which a caudal vertebra of *Trachodon* was identified. At this horizon, in the SW. ¼ SE. ¼ sec. 23, T. 41 N., R. 79 W., a dermal scute or skin plate of a large crocodile was obtained, but no other bones were found in the vicinity. A specimen of the same animal found in the Judith River formation of Montana has been described by Holland,[1] who has given it the name *Deinosuchus hatcheri*. He estimates that it was 35 to 40 feet long.

In 1916 the writer traced the Parkman sandstone from its typical exposures near Parkman, Wyo., northward to Yellowstone River in Montana, where he found that it connected with the sandy series which has been referred to the upper part of the Claggett formation and the Judith River formation.[2]

Teapot sandstone member.—Overlying the fresh-water beds just described is 325 feet of shale bearing at intervals marine fossils. Above the shale is the Teapot sandstone (Pl. VI, *B*), a comparatively fine grained bluish-white sandstone about 50 feet thick, with which are associated one or two beds of subbituminous coal. This coal is in most places too thin or too high in ash to be of commercial value. North of Shannon, in the NW. ¼ NW. ¼ sec. 32, T. 41 N., R. 78 W., it attains a thickness of 26 inches and was at one time mined for local use. The analysis of an air-dried sample is given below.

Analysis of air-dried sample of coal from Teapot sandstone in the NW. ¼ NW. ¼ sec. 32, T. 41 N., R. 78 W.

Proximate:	
Moisture	13.63
Volatile matter	32.61
Fixed carbon	38.19
Ash	15.57
Ultimate:	
Hydrogen	5.32
Carbon	50.81
Nitrogen	1.04
Oxygen	25.66
Sulphur	1.60
Ash	15.57
Calories	4,892
British thermal units	8,806

The Teapot sandstone is very uniform in character and extends over an enormous area. South of the Salt Creek field, along Teapot

[1] Holland, W. J., *Deinosuchus hatcheri*, a new genus and species of crocodile from the Judith River beds of Montana: Carnegie Mus. Annals, vol. 6, pp. 281–294, 1909.

[2] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds (with a chapter on the fossil plants by F. H. Knowlton): U. S. Geol. Survey Bull. 257, 1905.

Creek, it forms the high cliffs that overlook that stream, and at one place it has been carved by erosion into a tall pillar known to the early settlers in the region as the Teapot Rock, from which the creek was named. In the writer's former report on the Salt Creek field the sandstone was referred to as that of Little Pine Ridge, but the name Teapot sandstone has since been used in another report [1] and is here adopted as preferable. The bed is provisionally assumed to mark the top of the Mesaverde formation. Leaves have been collected from it, but no invertebrate fossils were found in it in the Salt Creek field.

LEWIS SHALE.

Above the Teapot sandstone is about 600 feet of marine shale, which contains at several horizons sandy beds. Upon this shale rests a sandstone about 100 feet thick, which is persistent throughout this general region. In some localities it is broken in its middle part by a bed of brown carbonaceous shale 6 feet thick. The sandstone below this bed is brown and weathers characteristically into small knobs and pillars. The sandstone overlying the shale is pure white.

Above this white sandstone is 600 feet of alternating sandstone and shale of marine origin. These beds appear to represent the Lewis shale of southern Wyoming. They are capped by a pure-white sandstone, 100 feet thick, which bears the marine plant *Halymenites* and is overlain by the fresh-water beds of the Lance formation. It occupies the position of the Fox Hills sandstone of other regions and probably represents the upper part, at least, of that formation. Associated with the sandstone are one or more coal beds, which are generally only a few inches thick but which in certain places (as, for example, in sec. 6, T. 38 N., R. 77 W., and sec. 4, T. 37 N., R. 78 W.) reach a thickness of 5 feet or more.

TERTIARY (?) SYSTEM.

LANCE FORMATION.

Above the Lewis shale are 50 feet of shale, sandstone, and thin coal beds, which appear to represent a transition from marine to fresh-water conditions. They are barren of fossils but are here included in the Lance. Above these lies the concretionary buff sandstone of the Lance formation (or "*Ceratops* beds") bearing the bones of *Triceratops* and *Trachodon*. The formation is about 3,200 feet in thickness.

[1] Hares, C. J., Anticlines in central Wyoming: U. S. Geol. Survey Bull. 641, p. 246, 1916.

TERTIARY SYSTEM.

EOCENE SERIES.

FORT UNION FORMATION.

The Fort Union formation as defined by the writer[1] in this region consists of about 2,000 feet of fine-grained bluish-white sandstone and gray shale containing at many horizons beds of ferruginous shale only a few inches thick. Its outcrop forms a prominent pine-covered ridge, which can be seen for many miles and is referred to in the region as Pine Ridge.

WASATCH FORMATION.

Above the Fort Union lies the principal coal-bearing formation of this region, which is believed to represent the Wasatch formation. It consists of alternating beds of yellow sandstone and gray shale, with here and there beds of coal. The upper part of the formation is exposed in the Pumpkin Buttes, the formation as a whole being about 2,400 feet thick. Near its base is a coal bed 17 feet thick, which is mined in a small way near the Puggsley ranch and which is the most valuable coal bed within reach of the Salt Creek field.[2]

STRUCTURE.

The Big Horn Mountains are flanked on the southeast by several anticlines, arches of strata that rise like a series of waves, each higher than the last, toward the major arch that forms the mountains themselves. On the easternmost—the outermost—of these anticlines is the Salt Creek oil field (Pl. I, in pocket), which obtains its oil principally from the Wall Creek sand. The pool in this sand occupies about 7 square miles on the crest of an arch that, considered in its entirety, covers several hundred square miles. The fold is not symmetrical, for its crest is much nearer its western than its eastern limit. The width of the eastern limb of the fold, measured from the crest to the bottom of the adjoining syncline, is about 20 miles, whereas the width of the western limb, measured from the crest to the bottom of the adjoining syncline, is only about a mile and a quarter. From northwest to southeast the Salt Creek anticline is approximately 30 miles long, but the present study considers only an area 16 miles long and 4 or 5 miles wide in its widest part.

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[1] For a discussion of the Fort Union-Wasatch problem in this region see Wegemann, C. H., Wasatch fossils in so-called Fort Union beds of the Powder River basin, Wyo., and their bearing on the stratigraphy of the region: U. S. Geol. Survey Prof. Paper 108, pp. 57–60, 1917 (Prof. Paper 108–D). In the former report on Salt Creek the beds here called Fort Union and Wasatch were all listed as Fort Union.

[2] Wegemann, C. H., The Sussex coal field, Wyo.: U. S. Geol. Survey Bull. 471, pp. 441–471, 1912.

The Salt Creek anticline is made up of three minor domes and two shallow intervening "saddles." The northernmost of these domes, the Salt Creek dome, is the largest and is outlined by the outcrop of the Shannon sandstone. The main Salt Creek field is on the crest of this dome and the old Shannon field is at its north end (Pl. III). The two remaining domes, which might almost be considered one and which will be referred to as the Teapot domes, are outlined on the east, south, and west by the rim rock of the Parkman sandstone. The southern dome is somewhat longer and larger than the northern. The Teapot domes are by no means in alinement with the Salt Creek dome, the axis of which extends practically northward, whereas that of the south Teapot dome extends about N. 20° W. The north Teapot dome is more nearly circular in outline than either of the others and is more nearly in alinement with its neighbor on the south than with the Salt Creek dome. Between this north dome and Salt Creek dome there appears to be an offset to the east, the anticlinal axis being bent (possibly with faulting) rather abruptly in that direction. The same type of folding is found in the Powder River and Kaycee domes, which lie west and northwest of Salt Creek. These domes may be considered as situated on one fold, the northern dome (the Kaycee) being offset to the west with reference to the dome of Powder River.

The fact that the dip of the east limb of the Salt Creek anticline is very much gentler than that of the west has an important influence on the depth of the oil sand below the surface. The axial plane of the fold slopes toward the east (Pls. I, II, in pocket), and the crest of the oil sand, which in the Salt Creek field lies about 1,000 feet below the surface, is therefore about a quarter of a mile farther east than the trace of the crest of the dome on the surface as indicated by the dips. In other words, a well drilled on the highest part of the fold at the surface would not strike the highest part of the fold in the oil sand but would be west of it.

The Salt Creek anticline, in spite of its asymmetric cross section, is extremely regular in outline as compared with anticlines in other oil regions. There are very few minor irregularities on its sides, and although faults occur they do not materially affect its general shape. Such minor irregularities as do exist appear to be gentle swells on the sides of the major fold. (See contour maps, Pls. I, II.) Their only effect on the accumulation of oil has been to extend the oil pool slightly in certain directions.

The beds on the west limb of the Salt Creek anticline dip steeply from the crest into the adjoining syncline. The part of this syncline that lies west of the north Teapot dome is broad and its axis pitches southward, in which direction the syncline grows broader and finally dies out altogether. Southwest of the main Salt Creek dome the syncline is broad and has no well-defined trough. In the area west of the main dome, however, the syncline is much more clearly defined, the strata plunging steeply from the dome for a distance of perhaps a mile and a quarter from its crest and then being abruptly bent upward, rising on the flank of the Powder River dome, the next fold to the west. Opposite the highest part of the Salt Creek dome the bottom of the syncline attains its highest point, from which its axis pitches both to the north and to the south. This part of the structure may really be considered a low cross fold connecting the Salt Creek and Powder River anticlines. It is not yet possible to say whether or not this high part of the syncline is due to folding or faulting. The Shannon sandstone, which crops out in a north-south escarpment about 6 miles west of the Salt Creek dome, is broken by numerous faults that trend a little north of east. These faults appear to extend well down into the syncline if they do not in fact cross it, and the peculiar shape of the bottom of the syncline indicated by comparison of logs of different wells drilled in it may be due to these faults. The broader parts of the syncline to the south, in which the beds have not been so abruptly flexed, does not appear to have undergone so much faulting, but this area has not been studied so carefully as the region farther north, and faults in it may have escaped observation.

The largest faults in the Salt Creek field cut the sandstone rim rock of the main dome. They are of the normal type, their planes being practically vertical, and their general course is N. 80° E. In several places about the dome faults occur in pairs, the intervening blocks of strata having been dropped. The amount of downthrow ranges from a few feet to 130 feet, and the horizontal displacement varies with the dip, the displacement on one fault on the southeast side of the dome having been as much as 2,670 feet. The faulting is notably pronounced at the southeast end of the main Salt Creek dome in the region of offset between this structure and the middle dome described above. Faults of similar nature and direction are found in the Shannon escarpment, which lies on the east flank of the Powder River dome about 6 miles west of the west rim of Salt Creek, and they were probably produced by the same forces that caused the faulting in the main dome. Many if not all the faults are marked by deposits of calcite, which appear to have filled open fissures several inches wide produced by the faulting.

Although most conspicuous in the rim rock, faults are also found in the shale within the rim rocks of the domes on the Salt Creek anticline. These faults in the shale appear to have a throw of only a few inches, or at most a few feet, their planes are practically vertical, and their direction is strikingly constant, being almost everywhere N. 70° E. The fissures formed by the faulting appear to range in width from a fraction of an inch to 3 or 4 inches. They were filled by calcite, with which, in some places in the oil field, thin flakes of a substance related to ozokerite, or mineral wax, is associated. (See p. 36.)

The time of the folding that produced the Salt Creek anticline is unknown, but as rocks of Wasatch age are involved in the fold on its eastern side, a part of the folding, at least, evidently took place during or after Wasatch time. Along the flanks of the major Big Horn uplift, which also is anticlinal, Wasatch strata are involved in the major mountain folding, so that the Salt Creek anticline may have been formed during the latter part, at least, of the uplift that produced the Big Horn Mountains. The relations of this fold and those of adjoining folds on the west to the Big Horn uplift as a whole are in accord with this view. Inasmuch, also, as the faults in the Salt Creek field appear to bear no direct relation to the shape of the fold, but cut across anticlines and synclines alike, all holding the same direction, a little north of east, it seems reasonable to assume that the faulting was subsequent to the formation of the anticline. It may be noted here, though the fact may be a mere coincidence, that the faults in Salt Creek are very nearly parallel to the larger axes of the intrusive masses in the Granite Mountains, mapped by Hares[1] in central Wyoming. The movement, whenever it occurred, was probably regional rather than local.

OIL.

SALT CREEK POOL.

THE WALL CREEK SAND AS AN OIL RESERVOIR.

Source of the oil.—The principal source of oil so far developed in the Salt Creek pool is the Wall Creek sand, which is reached on the crest of the dome at a depth of about 1,000 feet. The Wall Creek sand is reported to be about 125 feet thick in this area (it is certainly considerably over 100 feet) and consists of medium-grained dirty-gray sandstone containing thin calcareous beds and numerous lenses and layers of sandy shale ranging in thickness from a fraction of an inch to several feet. The distribution of the oil in the sand is probably dependent to a considerable degree on differences in the porosity of the layers composing it, due to differences in the sizes of the sand grains and the amount of cementing material between them. The porosity of the sand in the several layers of the formation differs greatly, as is shown by tests made by C. E. Van Orstrand of specimens collected in the Powder River field west of Salt Creek. A

[1] Hares, C. J., unpublished notes.

specimen of massive sandstone from the upper part of the Wall Creek has a porosity of 25.8 per cent; another specimen, somewhat shaly, taken near the base of the formation, has a porosity of 20.4 per cent; and a specimen from one of the thin layers of calcareous sandstone, called by the drillers "shells," has a porosity of only 7.6 per cent. The average porosity indicated by these three specimens is therefore 17.9 per cent, which represents the total porosity of the sand. Inasmuch as some of the spaces between the sand grains are entirely sealed by cementing material and thus cut off from other spaces, oil can not enter them, and they are therefore not effective in increasing the capacity of the sand. The "effective porosity" is thus seen to be considerably less than the total porosity.

The larger the grains of the rock the more rapidly the oil circulates through it and the better oil reservoir it makes. Owing to such variations in the character of the sand, oil is encountered in the wells in pay streaks; in some places the "pay" is found at the very top of the sand; in others it is found some distance below the top, only small amounts of oil and gas being found when the sand is first struck. The important fact remains, however, that there are no dry holes within the known oil pool, some part of the sand being capable of commercial production wherever it is tapped.

Distribution of the oil about the Salt Creek dome.—The distribution of the oil about the Salt Creek dome is unusually regular in comparison to the distribution of oil in the fields of many other regions. The line marking the contact of the oil pool with the water that occupies the sand on the flanks of the fold below the oil varies only about 150 feet in elevation in the entire circuit of the dome, lying between 3,425 and 3,575 feet above sea level. On the west side of the dome, where the dips are steep and the fold is regular in outline, the lower limit of the oil pool appears to lie at an elevation of 3,550 feet. In fact on three sides of the dome the variation is not over 50 feet. Only at the north end does the pool extend farther down the slope of the fold than at other places, perhaps because the oil at the north end may have been gathered from long slopes on the north and northwest as well as on the east and northeast, thus drawing on a greater volume of sand than other parts of the pool.

Gas in the oil.—The oil in the Wall Creek sand is a high-grade gasoline oil, with paraffin base, containing only a small quantity of asphalt. (See analyses, p. 41.) The oil under pressure contains a large amount of dissolved gas, which appears to be included in the body of the oil rather than to form a distinct pool above it. The wells near the crest of the dome, such as No. 1, in the NE. ¼ sec. 23, T. 40 N., R. 79 W., obtain a larger percentage of gas than those farther down the flanks, but all the wells in the pool flow from their own rock pressure, and the flow continues for years without pumping. This flow is to be attributed to the pressure of the dissolved gas, and the fact that all the wells show it would appear to indicate that the gas is comparatively evenly distributed throughout the oil of the entire pool.

Yield of the wells.—The wells differ greatly in initial production. One of the largest wells in the field is said to be No. 8 in the SE. ¼ sec. 23, drilled in 1915. This well came in with about 4,000 barrels a day. Another large well is No. 28, in the SW. ¼ sec. 13, T. 40 N., R. 79 W. The big flow in this well was struck in a soft streak 51 feet below the top of the Wall Creek sand. The Hanley & Bird well, in the northeast corner of sec. 3, T. 39 N., R. 79 W., and well No. 6, in the NW. ¼ sec. 36, are credited with an initial production of about 1,400 barrels. The well last named was drilled in February, 1912, and is said to have produced over 1,000,000 barrels of oil in five years. It is evident that a production so large must have drawn from the sand for a considerable area about the well. The first well drilled in any area doubtless has a marked advantage over wells drilled later, particularly if the oil is under high gas pressure, for channels leading to the well are established in the sand by the strong flow of oil, and after these channels are established the oil is not easily diverted from them to other wells that may be subsequently drilled in the vicinity.[1]

Flow of wells.—The flow of most if not all of the wells is periodic and the time between the periods may be only a few minutes. A well, say 1,000 feet deep, slowly fills with oil, the pressure in the sand increasing because of the accumulation of gas. When the pressure is sufficiently strong the column of oil in the well is raised and a part of it is expelled from the casing. After the gas pressure has been thus temporarily relieved the flow ceases and more oil flows into the bottom of the well from the sand. As the oil enters the well the high rock pressure which has kept the gas dissolved in it is lowered, and the gas is given off and accumulates in the well until it is capable of lifting the great weight of the column of oil above it, when a second flow takes place and the process is repeated. The wells being connected with the tanks, the oil is expelled into them and the necessity of pumping is avoided. (See Pl. VII, *B*.)

Recording pressure gages have been used in the field, and the records are most interesting. One well flows every thirty minutes, another once in an hour and forty-five minutes, and another flows so frequently that the gage records an almost continuous flow. The differences are doubtless due to differences in the depth of the wells and to variations from place to place in the porosity of the sand, which

[1] Thompson, A. B., Oil-field development, p. 136, 1916.

permit the oil to collect in one well more rapidly than in another. Differences in the gas pressure in different parts of the dome also have their effect.

Interference of wells.—Little information is available on the interference of wells that reach the sand in the Salt Creek field. Few wells have been drilled in the field in comparison to the size of the producing area, and interference has probably not yet become noticeable, though it is reported that when Hanley & Bird's large well No. 1, in the northeast corner of sec. 3, T. 39 N., R. 79 W., is shut in, Northwestern well No. 5, in the SW. ¼ sec. 2, T. 39 N., R. 79 W., will flow. Both are producing from the Wall Creek sand.

Several wells not far from the edge of the pool are now producing some water with the oil, and the quantity of water is apparently increasing, as is to be expected, for as oil is withdrawn from the reservoir water of necessity flows in to take its place. The fact that a well is making water does not of necessity condemn the territory outside of it, for in entering a thick sand like the Wall Creek a well may pass the oil horizon at the top of the sand and enter the water below. The presence of water indicates in a general way that the oil zone is comparatively thin and that the wells which make water will not be as productive or of as long life as those which yield only oil.

In several wells that yield both oil and water a peculiar rhythmic variation in the percentages of the two is noted. The combined production of oil and water remains practically the same from day to day, but for a period of three to four days the percentage of water increases up to a given maximum as the percentage of oil decreases, and then decreases to a minimum as the percentage of oil increases. This variation is repeated week after week. It is evident that increase in the percentage of water from a well indicates decrease in gas pressure on the oil adjacent to the well, which allows the water to rise in the sand and enter the well in larger quantity. Such decrease in gas pressure might be due to unusual drains on the oil reservoir by surrounding wells, it being the practice of the company to control the flow from individual wells to meet requirements. This would not, however, explain the periodic variation, which is evidently due to other causes and for which the following explanation of the phenomenon is here offered. In a well that is producing a much greater percentage of oil than of water the gas pressure may be steadily reduced by the escape of oil and gas for a certain number of days until it reaches a point where the water under hydrostatic head rises in the sand, shutting out part of the oil from the well and itself entering the well. Water once in the sand is with difficulty forced out by oil. As the production of the oil from the well is diminished by the cutting off of the flow by the water the rock pressure due to the influx of oil from surrounding territory gradually increases and the oil flows into the area of low pressure about the well faster than it can escape through the well. The rock pressure thus increases until it reaches a point where the pressure of the oil is sufficient to expel the water from the sand, permitting a freer flow of oil into the well, which again yields a higher percentage of oil for a certain period until the pressure is decreased, when the process is repeated.

Drilling and cleaning wells.—The time required by experienced men to drill a well in the Salt Creek pool is comparatively short, averaging under favorable conditions from 10 to 15 days for a 1,000-foot well. The drillers know in advance at about what depth the sand will be struck, and from the surface to the sand inside the rim rock there is nothing but shale. Two or three lengths of 10-inch casing are used, and from 500 to 800 feet of 8¼-inch casing; 6⅝-inch casing is set on the sand.

Most of the wells are shot with 100 to 200 quarts of nitroglycerin, and the production is thus greatly increased. Some wells that are several years old and that appear to become choked with mud and paraffin have been greatly improved by being cleaned out and deepened a few feet.

THE "LOWER WALL CREEK SAND" AS AN OIL RESERVOIR.

Since the greater part of this report was written deep wells drilled on the western border of the Salt Creek field have found oil in the so-called "Lower Wall Creek sand." The writer has not had the opportunity to examine the field since these wells were drilled, and the following notes are therefore based on reports of the drillers.

The first well to reach the "Lower Wall Creek sand," which lies 260 feet below the base of the Wall Creek sand, was drilled in the NW. ¼ sec. 27, T. 40 N., R. 79 W. The Wall Creek sand contained water, but the "Lower Wall Creek," according to reports, furnished a productive well.

The second deep test well was drilled on the Hjorth property, in the NE. ¼ SE. ¼ sec. 32, T. 40 N., R. 79 W. The well reached a depth of 2,765 feet and after encountering water in the Wall Creek sand came in as a 250-barrel well in the "Lower Wall Creek."

This last well is about a mile west of the axis of the syncline, which lies west of the Salt Creek dome, and was drilled at a place where the beds lie comparatively flat, the dip being only 125 feet to the mile, on the low arch or saddle that in a way connects the domes of Salt Creek and Powder River. Though the area of this arch is anticlinal, inasmuch as the beds dip away from it to the north and to the south, it is synclinal with reference to the dome on the east and that on the west, inasmuch as the beds rise from it toward these domes.

The oil that was encountered in the "Lower Wall Creek sand" in the Hjorth well, in sec. 32, probably found its way to this place up the rise of the beds from the syncline on the north and that on the south. When it reached the area of low dips on the broad, low arch that lies betwen the two domes the impelling force, the strength of which was dependent on the degree of inclination of the beds, was not sufficient to drive it farther, and it was therefore trapped and held in this vicinity.

The pool is probably continuous between the Hjorth well and the area of the main Salt Creek dome, but this remains to be proved. The distance to which the oil will rise along the flank of the Powder River dome probably depends on the extent of the area of low dips. Wherever the dips on the flank of this dome are high enough to cause the oil to work its way upward through the sand it was doubtless long ago forced up and lost in that part of the "Lower Wall Creek sand" which has been eroded from the crest of the Powder River dome. The limit of the advance of the oil toward the west has probably been in part fixed by water, which is doubtless entering the "Lower Wall Creek sand" along its outcrop in the Powder River dome, but the position of the line between the oil and the water is likely to depend on the amount of dip, inasmuch as the water will descend with more power where the dip of the rocks is steep than where it is low. In other words, when the water has advanced toward the east until it reaches the area of low dips above referred to its advance is likely to be stopped by the oil that occupies this area.

The prospector should therefore drill his first wells within the area of low dips, indicated on the map (Pl. II, in pocket) by the broad spacing of the contours. Where the dips are high and the contours are consequently closely spaced, the possibility of finding oil appears to be small.

The above statements refer only to the syncline west of the Salt Creek dome. A sufficient number of wells have already been drilled to indicate that the pool in the "Lower Wall Creek sand" is probably much larger than the pool in the Wall Creek sand. In other words, productive wells will probably be encountered in the "Lower Wall Creek sand" beyond the limits of the pool in the Wall Creek sand on all sides of the Salt Creek dome. The peculiar conditions of accumulation in the syncline, however, indicate that the oil here lies structurally lower than it does, for example, on the east side of the Salt Creek dome, where, because of the steep dips of the beds, the oil in the "Lower Wall Creek sand" will be impelled with greater force toward the crest of the dome and the sand will be filled to its utmost capacity with the oil, which will not be distributed through as wide an area of the sand. The Hjorth well was drilled between the 2,700 and 2,800 foot contours. If the above inferences are correct, water will be found on the east side of the dome between these contours, and the oil must be sought perhaps 200 or 300 feet higher on the flank of the dome. These statements are, of course, based on merely theoretical considerations, and their truth must be proved by drilling. They should indicate, however, the best places for drilling the first test wells.

The fact that the pool in the "Lower Wall Creek sand" appears to be of much greater area than that in the Wall Creek sand seems to have a most interesting bearing on the supposed migration of oil from shale into sand. The Wall Creek sand is reported to be 125 feet thick and is certainly considerably over 100 feet, whereas the "Lower Wall Creek" is only 20 or 25 feet thick. The fact that the pool in the "Lower Wall Creek," which is the thinner sand, is much larger than that in the Wall Creek would suggest that the quantity of oil collected by the sands did not depend on their thickness and volume. It may depend on the area of the upper and lower surfaces of the sand that lies in contact with the shale. If so, probably only the shale immediately adjacent to the oil sand supplied the oil which is later found in the sand, and the amount of oil which thus migrates from the shale into the sand may be as much dependent on the porosity and other physical features of the shale as on the amount of bituminous material which the shale contains.

SHANNON POOL.

As stated on page 7, the first commercial wells in the Salt Creek field were drilled in the Shannon pool, which is at the north end of the dome, about 3 miles north of the present town of Salt Creek. (See Pl. III.) The oil is obtained from the Shannon sand, which lies 2,000 feet above the Wall Creek and forms the rim rock of the Salt Creek pool. The Shannon sand is encountered in the wells at Shannon at depths ranging from 700 to 1,000 feet. As seen in the rim rock and as reported in the wells it consists of two ledges separated by 30 or 40 feet of sandy shale. The upper ledge of sandstone is about 40 feet thick and the lower one 50 feet. The oil is confined to the lower ledge, the upper being water bearing. The porosity of the sand as determined by C. E. Van Orstrand is 26.7 per cent.

In drilling the wells a water-bearing sand from 30 to 50 feet thick is encountered 400 feet above the Shannon—doubtless the same sand that forms the first ridge outside the rim on the northeast side of the dome. (See p. 11.) In the deep test well that was drilled 625 feet northwest of No. 1 (Pl. III) to a depth of 2,345 feet a 7-foot sand which produced a little water was struck 650 feet below the base of the Shannon. This sand is probably the equivalent of that in sec. 14, T. 40 N., R. 79 W., described on page 20.

The Shannon wells are small, the average well producing daily from 5 to 15 barrels of heavy paraffin-base oil. The pool appears to have been fairly well outlined and contains not more than 160 acres. Some of the wells flowed slightly when first struck, but all of them were pumped. No oil is now being taken from them.

The pool is on the pitching north end or "nose" of the Salt Creek anticline, at a place where the fold is narrowed rather abruptly. The oil extends farther down the end of this fold than it does on the western flank. The limits on the east are not accurately determined. Just why the oil should have been retained here rather than have worked its way up the dip to the outcrop of the sand to escape there is not altogether clear. A pronounced flattening of the dip just south of the pool might retard the upward migration of the oil and cause it to accumulate, but the information at hand indicates no such flattening. Again, several southwestward-trending faults noted on the southeast edge of the pool may have broken the sand sufficiently to stop the southward flow of the oil. Still again, water entering the sand along the outcrop might have worked down the dip, flooding the sand and confining the oil in the pool where it is now found. This explanation of the conditions seems to be somewhat more plausible than the other two just suggested.

TEAPOT OR SADDLE ROCK POOL.

Relation to Salt Creek pool.—The Teapot or Saddle Rock pool is on the southern extension of the Salt Creek anticline and is separated from the main Salt Creek pool by a structural depression that lies southeast of Frewen's Castle. The Teapot anticline is itself divided into two domes, the crest of one of which lies in secs. 3 and 10, T. 38 N., R. 78 W., and the other in secs. 28 and 33, T. 39 N., R. 78 W. The northern dome is therefore about 4 miles southeast of the south end of the Salt Creek oil pool.

Oil from the Shannon sand.—The sands in the Teapot anticline have not been thoroughly tested for oil, but the presence of oil in them is easily inferred from the structure, and the fact that the fold may contain an oil pool was suggested by the writer in his former report on Salt Creek.[1] Since that report was written several wells drilled in T. 38 N., R. 78 W., to the Shannon sand have demonstrated the presence of oil in that sand on the southern dome. The sand in the northern dome and the shallow "saddle" that separates it from the southern dome has not yet been tested, but oil is likely to be

[1] Op. cit., p. 77.

found in both domes. Shows of oil were encountered in two wells drilled to the Shannon sand in the SW. ¼ sec. 4 and the NE. ¼ sec. 16, T. 38 N., R. 78 W. The well in sec. 16 struck the sand at a point on the west flank of the fold about 800 feet below the crest. This showing would seem to indicate a fairly broad distribution of oil in the sand, but the map (Pl. I) shows that the Teapot fold is much smaller and lower in absolute altitude than the main Salt Creek dome, and its oil content is therefore probably less than that of the Salt Creek dome. It is questionable whether the "saddle" between the north and south Teapot domes contain oil, particularly as it appears to be lower than the saddle between the north Teapot dome and the Salt Creek dome—a saddle that appears to be barren of oil in the Wall Creek sand so far as indicated by drilling done within the Shannon escarpment south of the Salt Creek pool. Because of the scarcity of rock exposures in the valley of Teapot Creek northwest of the north dome, it is practically impossible to work out in detail the structure in this vicinity. Extensive faults may have broken the oil-bearing sands between the north dome and the Salt Creek dome, but their presence can be inferred only from the sharp bend in the anticlinal crest in this vicinity and from certain peculiarities in the distribution of the few outcrops which exist. If faults are present, they would probably constitute a barrier that would prevent the migration of oil from the Teapot dome to the higher Salt Creek dome.

Oil in the Wall Creek sand.—Thus far the possibility of obtaining oil in the Teapot domes from the Shannon sand only has been considered; the Shannon, if we can judge by what it has yielded in the Shannon pool, will not afford very large wells. The Wall Creek sand, which lies 2,000 feet below the Shannon, should be reached at about 2,450 feet on the crest of the south Teapot dome, and there is apparently no reason why this sand should not be as productive here as it is in the Salt Creek pool, to the north. It is true that the crest of the Teapot anticline is somewhat narrower than that of the Salt Creek, and that the top of the Wall Creek sand in it is about 1,500 feet lower than it is in the Salt Creek pool, but the east limb of the Teapot fold is practically as long as that of Salt Creek, and the structure would therefore permit oil to be drawn from a large area to the south just as in the Salt Creek fold it is drawn from a large area to the north. The structural depression north of the north dome and the faults that are believed to interrupt the sand at that place probably would not permit oil that has once reached the Teapot fold to be forced into the Salt Creek dome, although that dome is much the higher. The Wall Creek sand in the Teapot domes may therefore perhaps eventually prove to be as productive as the same sand in the Salt Creek pool. The extent of the pool in the lower sand can, of course, only be inferred from the probable extent of the pool in the Shannon sand, and this is by no means a sure guide.

OIL FROM FISSURES IN THE SHALE.

In practically all the wells drilled in the Salt Creek field more or less oil is encountered in the shale at different depths. These depths do not correspond in adjoining wells, and a comparison of logs shows that the oil is not obtained in porous beds within the shale but from some other source. The shale is so fine grained that it would not in itself constitute a reservoir for oil, as the openings between the particles are too small to permit oil to flow rapidly through them. Some wells in the Salt Creek field have obtained oil from the shale in large quantities, a few obtaining 1,500 barrels or more a day, indicating that the openings from which the oil is supplied to the wells are large enough to allow rapid flow. A comparison of analyses of the oil from the shale with analyses of the oil from the Wall Creek sand shows that the two are practically identical, the only difference being that the oil from the sand contains a little more dissolved gas.

In "drilling in" the shale wells, which start flowing under considerable pressure, it is often noticed that fragments of calcite are ejected from the wells. The calcite is like that which fills or partly fills the fissures produced by faulting in the shale. All the phenomena of the known shale wells indicate that the oil in them is derived from fissures in the shale, and that this oil is derived from the Wall Creek sand below. Certain of the faults in the shale extend down to the sand and afford passages through which the oil in the sand, under great pressure, has been forced upward into the shale. As the fissures in the shale are not confined to the dome itself but extend into the adjoining syncline on the west oil has been forced laterally through the fissures into the shale of the syncline, in which it is encountered in commercial quantities in wells drilled in the shale. The Wall Creek sand, wherever it has been reached in this area, has produced water.

The ozokerite, or mineral wax, that is associated with the calcite which fills all fault fissures at the surface is produced by the evaporation of oil which has risen in these fissures and long remained there. It is noteworthy that the deposits of ozokerite appear to be confined to the dome above the oil pool and are not found in the adjoining synclines in which shale oil is encountered, perhaps because the gas pressure immediately over the oil pool was the greatest and the oil was forced close to the surface, whereas at greater distances from the pool the pressure was not so great and the oil was not forced upward to produce seepages and deposits of ozokerite.

DANGER OF THE ESCAPE OF OIL FROM THE WALL CREEK SAND INTO FISSURES IN THE OVERLYING SHALE.

As has been shown in preceding pages, the shale above the Wall Creek sand is fractured by many faults and probably contains many fissures unfilled by either oil, water, or calcite. There can be little question that faults which break the oil sand and throw its broken edges against impervious shale beds partly or wholly seal the sand along the fault planes so as to prevent the migration of oil across them. If the broken edges of the beds are left even slightly separated oil will find an easy passage through the fissure, but if the edges are compressed against each other or if the fissure is filled with calcite or other deposits, the fault forms an impervious barrier to the migration of oil in certain directions. Were these fissures all connected with one another or with the Wall Creek sand below, they would probably long ago have been filled with the oil which is now held under great pressure in the Wall Creek sand, and in filling the fissures a large part of the oil in the sand would doubtless have been dissipated. Several wells in the Salt Creek field were drilled to the sand and afterward capped and allowed to remain idle. When first drilled these wells may have shown considerable gas pressure and consequent large production of oil, but on being opened several weeks or several months later it was found that the pressure had decreased in some of them and that these wells were comparatively small producers. The explanation is obvious. A well drilled through the shale to the sand passes through one or more fault fissures, and as the casing is not firmly set in the hole the oil, under pressure in the sand, finds its way around the outside of the casing up to these fissures, gradually filling them. By this process the oil in the area drained by the well is in large part dissipated through these openings in the shale, the pressure is diminished, and the production of the well is greatly reduced. On entering the fissures the oil is in part doubtless absorbed by the shale on the sides of the fissures and so held in the rock, from which it can never be recovered. It is reported that during one cold winter the 2-inch line from well No. 6, in the NW. ¼ sec. 36, T. 40 N., R. 79 W., became choked with paraffin, virtually shutting the oil in, so that within a few hours oil seeps appeared at the surface 200 feet west of the well. A pit was then dug at the seeps and oil was pumped from it at the rate of several hundred barrels a day. When the clogged line from the well was opened the oil ceased to rise in the pit.

There can be no doubt that the life of the field and its production will be greatly increased by care in the proper setting of casing upon the sand. The additional expense involved by this care will probably be many times repaid by the resulting prolongation of production.

SURFACE INDICATIONS OF OIL IN THE SALT CREEK FIELD.

Surface indications of oil in the Salt Creek field may be divided into three classes—oil and gas seeps in the shale, deposits of ozokerite or mineral wax along fault planes in the shale, and oil seeps from the Shannon sandstone. Several oil and gas seeps from the shale were known prior to the drilling of the discovery well in the Salt Creek anticline. One seep known as the Iba oil spring was in the bed of Salt Creek in the SE. ¼ SW. ¼ sec. 13, T. 40 N., R. 79 W. Concerning it Samuel Aughey,[1] Territorial geologist of Wyoming, wrote in 1884:

> When I last visited this spring in May, 1884, not less than 20 barrels of oil had accumulated in the creek bed. The rise of the creek from a rainfall one night washed it away, but it immediately commenced again to accumulate and in less than a week the original quantity was stored.

When this seep was first visited by the writer in 1909 oil did not collect in noticeable quantity in the creek bed. The site of the spring was marked by a small sand bar in the middle of the creek at a point where the creek bends to the north and has on its east a high cut bank. The sand was black and greasy on the surface and when dug into emitted the odor of petroleum.

On Castle Creek, a little above its junction with Salt Creek, in the SW. ¼ sec. 25, T. 40 N., R. 79 W., the sand and gravel along the stream bed are saturated with oil.

It is reported that the Dutch No. 1 well was drilled beside a large oil seep that is now concealed by the oil reservoir south of the well.

A gas seep in the bed of Salt Creek occurs in the SW. ¼ NW. ¼ sec. 25, T. 40 N., R. 79 W., just north of the mouth of a draw that comes in from the southwest. Bubbles of gas rise at intervals through the water and spread an oily film on its surface.

The oil and gas that found their way to the surface in the seeps described above probably traversed fault planes or fault fissures in the shale from the Wall Creek sand below. They are merely surface indications of the oil that is struck in many of the wells that cut through faults in the shale. As stated above, they are found only above the oil pool on the dome, probably because the pressure in the oil sand was greater above the dome than on either flank of the dome and, therefore, forced the oil to the surface only immediately above the oil pool in the direction of least resistance.

Layers of ozokerite, or mineral wax, ranging in thickness from an eighth to a half inch, are at many places on the surface of the dome associated with the calcite that fills the fault fissures in the shale. The mineral wax is black, its color being presumably due to the presence in it of a small percentage of asphalt. This wax, which is found at the surface in fissures that doubtless contain oil below the surface, appears to be merely the residue left by the evaporation of

[1] Wyoming Territorial Geologist Ann. Rept., 1886.

the oil. Oil and calcite are found together in fault fissures in other fields. The writer has seen crystals of calcite from northern Mexico that contain globules of oil.

On the Teapot or Saddle Rock dome ozokerite is associated with calcite precisely as it is on the main Salt Creek dome, but the ozokerite on the Teapot dome is derived from the evaporation of oil from the Shannon sandstone. This oil contains a higher percentage of paraffin and no asphalt, so that the ozokerite derived from it is rich amber in color and semitransparent. Lumps of it 2 inches or more thick have been collected in the SE. ¼ SE. ¼ sec. 10, T. 38 N., R. 78 W. Similar deposits are reported also in sec. 3, T. 38 N., R. 78 W.

Oil is seeping from the Shannon sandstone itself in at least three places on the rim rock at the north end of the Salt Creek dome. One of these seeps is near the head of a gulch or draw in the SW. ¼ NW. ¼ sec. 12, T. 40 N., R. 79 W. The seep here is at the base of 8 feet of oil-saturated sandstone. The sand is coarse, shows marked cross-bedding, and contains particles of some dark mineral. The basal bed of sandstone is massive, but most of the higher beds are not more than 8 or 10 inches thick. The sandstone contains numerous calcareous and siliceous lenses.

In the NW. ¼ SE. ¼ sec. 11 of the same township there is an oil-saturated sandstone which is probably the same bed as that just described at the head of the gulch.

Two oil seeps occur in the NE. ¼ SW. ¼ sec. 11, just west of the one last mentioned. The southern seep is at the outcrop of the oil sand, but the northern one is in shale. The oil probably rises through the shale from the oil sand below.

In the SW. ¼ SW. ¼ sec. 11 the following section of the oil sand is exposed:

Section of Shannon sandstone in sec. 11, T. 40 N., R. 79 W.

	Feet.
Sandstone, oil bearing, top concealed	3
Shale, blue	5
Sandstone, saturated with oil	5
Sandstone, oil stained	4
Shale, dark.	
	17

ORIGIN AND ACCUMULATION OF THE OIL.

The oil in the Salt Creek field was probably derived from the remains of small sea plants or animals which were buried in the thick beds of Cretaceous mud that formed the Colorado and Montana shales. Possibly the remains of vertebrates, such as fishes or saurians, may have contributed some oil, but in view of what is known of the origin of oil in other fields, this possibility seems rather doubtful. The remains of immense numbers of algae have been discovered in the oil shales of Colorado,[1] and the carbonaceous material in these shales, which upon distillation yield petroleum, was probably derived from these minute plants.

The oil of the Wall Creek sand was probably derived from organisms that were different from those which produced the oil in the Shannon sand, although many authorities would account for the differences in the oils by supposing that they were filtered through sediments of different kinds or different grain.

As sandstones are sorted and put down in water in which currents are active, and as shales are deposited farther from shore, in comparatively still water, the conditions for the growth of small plants or animals were not so favorable where sandstone was deposited as where shale was deposited. Sandstone contains relatively few fossils, and it is therefore assumed that oil probably originated in shale rather than in sandstone. As the oil is now found in sandstone rather than in shale, it is assumed that it was driven from the shale into the sandstone by partial distillation produced by heat or by the great pressure involved in earth movements, or by the action of ground water, which forced it from one sediment into another, or by some other unknown cause. That the oil, once in the sandstone, is forced up the dip and held near the crests of domes or anticlines, there can be no question. Its upward movement may be due to the difference in capillarity between oil and water, to the difference in specific gravity between oil and water, or to other causes. All attempts to explain the mode of origin and accumulation of oil still remain in the realm of speculation.

As the Colorado and Montana shales are of very uniform character over wide areas the oil-producing organisms were probably everywhere present within them, so that the production of oil depended on forces that acted upon the shale only in certain localities, for oil is not found in every sandstone of the Colorado and Montana groups even where the sandstone is bent into suitable folds for its accumulation.

Assuming, then, that oil was produced only in the vicinity of certain folds and that it found its way from the shale into the sandstone, it is evident that the quantity of oil migrating into the sandstone will depend on the area of the shale in contact with it. Oil can be collected on the crest of a dome only from the sandstone which is involved in that dome provided the sandstone contains water as well as oil—that is, oil does not pass downward through a sandstone bed, across a syncline, and into an adjoining fold. So far as we know oil, where it is backed by water, always rises up the dip, so

[1] Davis, C. A., Some fossil algae from the oil-yielding shales of the Green River formation of Colorado and Utah: Geol. Soc. America Bull., vol. 27, p. 159, 1916.

that the oil in the crest of any fold is derived only from the sandstone between that crest and the troughs of the adjoining synclines. The fact that a fold has at least one long limb is an indication that the accumulation in that fold will be larger than that in a fold whose limbs are short. The Salt Creek anticline, from which the rocks dip regularly for 20 miles to the northeast, has doubtless collected oil from an enormous area of the Wall Creek sand in which the oil is found. The sand in its turn had collected the oil from the shale, which is adjacent to it. As the west limb of the Salt Creek dome is only one-twentieth as long as the east limb it is probable that only one-twentieth of the oil in the dome was derived from the mass of the sandstone that forms the west limb. Assuming, therefore, that the greater part of the oil came from the east, it is to be expected that minor rolls on the east flank of the dome will be more likely to contain oil than similar rolls on the west.

ANALYSES OF OIL.

The following analyses of two samples of oil from the Wall Creek sand in the Salt Creek field show that the oil is of high grade:

Results of tests of oil from the Wall Creek sand, Salt Creek pool, Wyo.

[Analyses by the Bureau of Mines.]

	1	2
Oil used in test .... cubic centimeters..	100	100
Distillation:		
First drop at .... ° C..	32	35
To 50° C. .... cubic centimeters..	2.0	1.0
50° to 75° .... do....	3.0	2.5
75° to 100° .... do....	3.5	4.5
100° to 125° .... do....	6.0	6.0
125° to 150° .... do....	6.0	5.5
Total to 150° .... do....	20.5	19.5
150° to 175° .... do....	6.0	5.0
175° to 200° .... do....	7.5	5.0
200° to 225° .... do....	6.5	4.0
225° to 250° .... do....	4.0	5.0
250° to 275° .... do....	11.5	5.5
275° to 300° .... do....	11.5	7.0
Total 150° to 300° .... do....	47.0	31.5
Residuum .... do....	32.5	49.0
	....	100.0
Specific gravity:		
Crude	0.8348	0.8323
To 150°	.7280	.7260
150° to 300°	.8230	.8110
Residuum	.9130	.8970
Asphalt .... per cent..	2.77	0
Paraffin .... do....	6.93	9.59

1. Well 22, NW. ¼ sec. 2, T. 39 N., R. 79 W.
2. Well 31, NE. ¼ sec. 26, T. 40 N., R. 79 W.

WATER IN THE OIL SANDS.

Analyses of the waters associated with the oil in the Wall Creek and Shannon sands of the Salt Creek field have been made by S. C. Dinsmore. The writer is indebted to R. C. Wells and R. V. A. Mills for the following discussion of these analyses:[1]

The most obvious fact shown by the analyses is that the deeper waters—those from the Wall Creek sand—are more concentrated. The mean of the total solids of the three waters from the Shannon sand is 4,343 parts per million; the mean of the six waters from the Wall Creek sand, as shown in the second table below, is 8,732. The individual samples show some variation in concentration, possibly due to the fact that the samples may not have been taken from exactly the same stratum. Moreover, consideration has not been given to the production, the history, or the age of the well from which a sample was taken.

Analyses of waters from Shannon and Wall Creek sands.

[Parts per million. S. C. Dinsmore, analyst.]

	1	2	3	4	5	6	7	8	9
Total dissolved solids	3,356	3,438	6,236	11,232	6,048	10,390	3,846	12,554	8,326
SiO_2	88	96	104	106	88	74	72	94	114
Fe	....	....	9	....	....	....	....	....	....
Ca	20	18	36	24	12	18	14	14	16
Mg	6.9	3.8	8.6	19	9.1	20	4.8	16	11
Na	1,028	1,136	2,276	4,399	2,295	3,974	1,689	5,420	3,120
K	20	41			25	32	31		32
CO_3	84	312	168	384	252	240	384	648	360
HCO_3	536	2,098	707	3,928	2,793	2,634	3,050	5,440	2,659
SO_4	1,788	266	3,366	629	71	2,868	32	1,045	532
Cl	38	484	500	3,502	1,883	2,340	430	3,643	2,780
HS	5.4	45	4	....	.6	1	Trace.	....	2

1. From Shannon sand, SW. ¼ NW. ¼ sec. 34, T. 40 N., R. 79 W. One of the wells furnishing the water supply for the town of Salt Creek.
2. From Shannon sand, SE. ¼ NE. ¼ sec. 2, T. 40 N., R. 79 W. Just west of the Shannon pool.
3. From Shannon sand, SE. ¼ SE. ¼ sec. 36, T. 41 N., R. 79 W. Just northwest of the Shannon pool.
4. From Wall Creek sand, S. ½ SW. ¼ sec. 13, T. 40 N., R. 79 W. Wells 29, 29x, 32, and 33, all of which flow into one tank and part of which yield water as well as oil.
5. From Wall Creek sand, N. ½ SW. ¼ sec. 13, T. 40 N., R. 79 W. Wells 5, 6, 7, 16, 17, 18, all of which flow into one tank and part of which yield water as well as oil.
6. From Wall Creek sand, SE. ¼ sec. 25, T. 40 N., R. 79 W. Well 33; yields both oil and water.
7. From Wall Creek sand, NE. ¼ SE. ¼ sec. 22, T. 40 N., R. 79 W. Well 13.
8. From Wall Creek sand, NW. ¼ sec. 2, T. 39 N., R. 79 W. Well 22; yields both oil and water. Sample taken from tank containing steam coil.
9. From Wall Creek sand, SE. ¼ sec. 25, T. 40 N., R. 79 W. Wells 19, 29, 30, 31, all of which flow into one tank and part of which yield water as well as oil.

[1] For a more complete discussion of the general subject of the evaporative action of natural gases see Mills, R. V. A., and Wells, R. C., The evaporation of water at depth by natural gases: Washington Acad. Sci. Jour., vol. 7, pp. 309–310, 1917; also a report in preparation by the same authors for publication by the United States Geological Survey.

Total solids in waters from the Shannon and Wall Creek sands.

[Parts per million. S. C. Dinsmore, analyst.]

Shannon:	
Sample 1	3,356
Sample 2	3,438
Sample 3	6,236
Mean	4,343
Wall Creek:	
Sample 4	11,232
Sample 5	6,048
Sample 6	10,390
Sample 7	3,846
Sample 8	12,554
Sample 9	8,326
Mean	8,732

The general difference in the concentration in the waters from the two sands is probably due chiefly to the fact that surface water has entered the Shannon sand. On the other hand, the deeper waters are very favorably situated for concentration by the evaporative action of escaping gases, for the gas pressure in the deeper strata and the presence of relatively impervious layers would probably exclude surface water. The waters of both classes, however, are considerably more concentrated than an ordinary surface water. If the strata containing the water have been subjected to high temperatures, especially while gases were being generated, the water would have been partly removed as vapor by distillation and convection, leaving the more concentrated solutions now found. Under such conditions the degree of concentration would seem to depend upon the relative amounts of water and gas in the strata at any given time or the relative amounts brought in from deeper or more distant strata. Water vapor and gas are both very mobile, and the proportion of water vapor that can be transported by gas increases rapidly as the temperature rises. Gas that is escaping upward from deep sources would, in general, encounter rocks of progressively lower temperatures, but to offset this diminution of temperature the expansion of the gas due to the reduction of pressure would give it a greater capacity for retaining moisture. Large quantities of escaping gas would perhaps evaporate brines even to dryness, although no evidence of this action has been noted in this field.

The following tables contain a calculation of the salt constituents into reacting values,[1] or milligram equivalents per liter. It appears

[1] For definition of terms and factors see Stabler, Herman, Some stream waters of the western United States: U. S. Geol. Survey Water-Supply Paper 274, p. 167, 1911; also Palmer, Chase, The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, 1911.

from these values that some of the basic and acid constituents do not balance exactly. A calculation of the proportion of the various acid constituents is also shown.

Reacting values, or milligram equivalents per liter, approximately, in waters from Shannon and Wall Creek sands.

	1	2	3	4	5	6	7	8	9
Fe			0.3						
Ca	1	0.9	1.8	1.2	0.6	0.9	0.7	0.7	0.8
Mg	.5	.3	.7	1.6	.8	1.6	.4	1.3	1.0
Na	44.7	49.4	99.0	191.3	99.8	172.8	73.4	235.8	135.7
K	.6	1.1			.6	.8	8		.8
Sum of bases	46.8	51.7	101.8	194.1	101.8	176.1	75.3	237.8	138.3
CO_3	2.8	10.4	5.6	12.8	8.4	8.0	12.8	21.6	12.0
HCO_3	8.8	34.4	11.6	64.4	45.8	43.2	50.0	89.2	43.6
SH	.1	1.3	.1						
SO_4	37.3	5.5	70.1	13.0	1.5	59.8	.7	21.8	11.1
Cl	1.1	13.6	14.1	98.8	53.1	66.0	12.1	102.8	78.4
Sum of acids	50.1	65.2	101.5	189.0	108.8	177.0	75.6	235.4	145.1

Percentages of the typical acid constituents in waters from Shannon and Wall Creek sands, expressed as reacting values.

	1	2	3	4	5	6	7		9
r{CO_3, HCO_3, SH}	23.4	70.7	17.0	40.8	49.9	28.9	83.2	47.1	38.4
rSO_4	74.5	8.4	69.1	6.9	1.3	33.8	.8	9.2	7.6
rCl	2.1	20.9	13.9	52.3	48.8	37.3	16.0	43.7	54.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

When the proportions and concentrations of the constituents of the waters are compared, especially those of the acid constituents, the following facts become apparent:

1. The proportion of sulphates is decidedly variable but averages considerably higher in the Shannon than in the Wall Creek waters, owing, perhaps, to the greater oxidation near the surface. Small quantities of hydrogen sulphide, however, are reported in these waters.

2. The deeper waters are considerably more concentrated in carbonates and chlorides than the shallower waters. If the deeper water were forced upward into fissures above, release of pressure would doubtless allow carbon dioxide to escape and would result in the deposition of calcite, which is actually found in the fault fissures in the shale. What would become of the remaining water and its salt is problematic. The higher waters show a slightly larger ratio of carbonate to bicarbonate than the lower waters, a fact indicating that more carbon dioxide had escaped from them.

3. On account of the high concentration of carbonate and bicarbonate the concentration of calcium in both the deep and the shallow

waters is low as compared with that in surface waters generally. All the waters are probably substantially saturated with calcite, but the lower waters are more concentrated in bicarbonate and less concentrated in calcium than the upper waters. On exposure to the atmosphere any of these waters would lose much carbon dioxide.

4. In all the waters under consideration primary alkalinity[1] is prominent and, as would be expected, the content of silica is high. No definite relation can be established between the degree of primary alkalinity of the waters and their actual content of silica.

5. None of the waters appears to be saturated with gypsum if their content of gypsum is compared with that in various salt solutions.[2]

ESTIMATES OF FUTURE PRODUCTION.

Salt Creek pool.—Any estimate of the future production of an oil field as newly developed as that of Salt Creek, particularly one where drilling has been restricted, as it has been in this field, must be little better than conjectural. Nevertheless, such an estimate has value if it is used with a full understanding of the uncertainties involved in its determination.

The Midwest Refining Co. courteously furnished records of the monthly production of certain wells in the Salt Creek field. Assuming that all these wells were drilled on the same date and totaling the production by months, the writer has constructed a curve (fig. 1) which shows the rate of decline in the production of these wells and represents with fair accuracy the life history of the average flowing well in this field. The curves in figure 2 (p. 47) represent individual wells in the field.

From January to July, 1915, inclusive, 71 wells in the Salt Creek field produced 2,190,664 barrels of oil, an average per well of about 4,400 barrels a month. The average initial production of all wells in the field is not at hand. As drilling progresses the initial production of the wells will evidently increase, and probably the average above given (4,400 barrels) is a fair estimate of the average initial production of all wells when the field is completely drilled. Assuming, therefore, that the average well starts at 4,400 barrels a month, and applying the curve of figure 1, we find that the average well will produce 126,084 barrels in eight years, when it will be reduced to a pumping well producing only a few barrels or be practically exhausted.

The productive area of the Wall Creek sand in the Salt Creek field as now outlined is about 5.39 square miles, or 3,450 acres. By the present practice of the Midwest Co. 36 wells are drilled on each quarter section, so there is room for 776 wells in the pool. If each of these wells produces during its life 126,084 barrels of oil, the total

[1] For definition of this term see Palmer, Chase, The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, 1911.

[2] Seidell, A. Solubilities of inorganic and organic substances, p. 100, Van Nestrand, 1907.

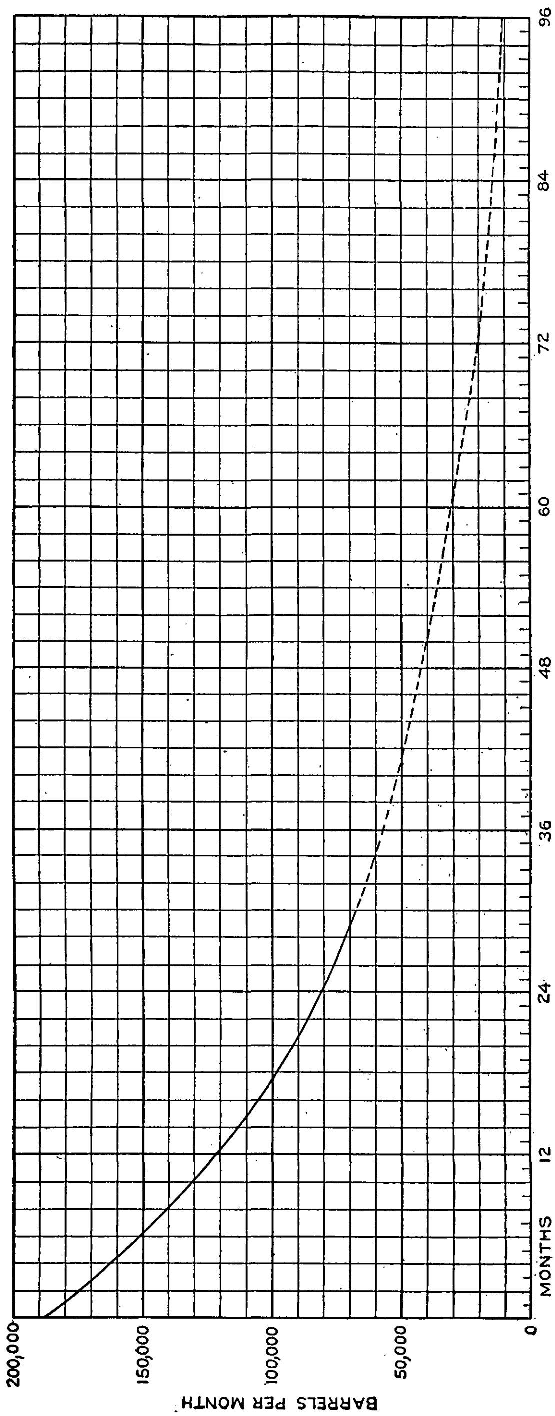

FIGURE 1.—Curve showing average production of 71 wells in Salt Creek field. Dotted portion is hypothetical projection of curve beyond point at which available data end.

production of the field will be 97,841,184 barrels. In this figure no account has been taken of the interference of wells with one another, which will doubtless have a marked effect as the pool is more completely drilled, although at present most of the wells are so widely separated as to have little or no effect on one another. If we make a

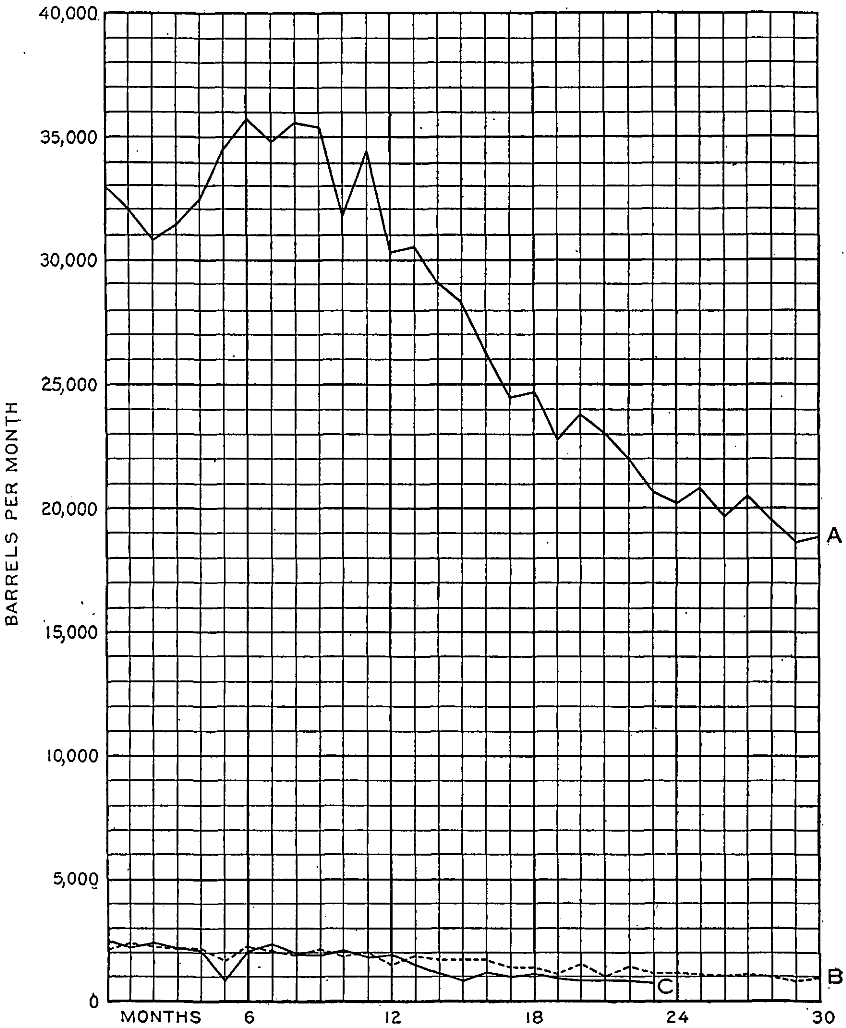

FIGURE 2.—Individual production curves of three wells producing from Wall Creek sand in Salt Creek field.

reduction of about 18 per cent for this interference, we have as the possible production of the Wall Creek sand in the Salt Creek pool the grand total of 80,000,000 barrels of oil.

This figure can be checked by an estimate of the porosity of the sand. Assuming that the Wall Creek sand is 125 feet thick, 5.39 square miles of the sand would include 18,783,072,000 cubic feet of sandstone. Assuming that the average porosity is 18 per cent (see p. 28), this sandstone would represent 3,380,952,960 cubic feet of pore space. Assuming, also, that only 12 per cent of this space is filled with oil that can be recovered by drilling, we find that the quantity of recoverable oil is 72,255,450 barrels, as against 80,000,000, determined by the other method. As 12 per cent is probably a low estimate for the space filled with oil, we may assume that the estimate of 80,000,000 barrels for the total production of the Wall Creek sand in this pool is approximately correct. The pool had produced, up to January 1, 1917, 15,200,000 barrels, and is therefore 19 per cent exhausted.

In the above estimates of the oil content of the Salt Creek pool no account has been taken of the possibility of obtaining oil in the so-called "Lower Wall Creek sand." This sand, as shown on page 18, lies about 260 feet below the base of the Wall Creek and is about 25 feet thick. It has been reached by only one well in the Salt Creek field, which was drilled in the NW. ¼ sec. 27, T. 40 N., R. 79 W., and obtained a fair showing of oil from the lower sand. In a sand only 20 feet thick the oil would probably occupy pore space throughout the bed, and an estimate that 20 per cent of the oil is recoverable is perhaps not too high. Assuming that this sand has the same porosity as the Wall Creek, and assuming also that the pool in the so-called "Lower Wall Creek" is no larger than that in the Wall Creek, we may estimate the available oil in the "Lower Wall Creek" at 25,000,000 barrels. The presence of a pool of this size in the "Lower Wall Creek," although it appears to be highly probable, remains to be shown by drilling.

Shannon pool.—Sufficient data for an estimate of the probable future production of the Shannon pool are not yet available, and an estimate will therefore not be attempted. The pool is comparatively small and appears to have been about half drilled in. The oil is heavier than that in the Salt Creek pool and therefore does not flow through the sand as readily, but as the value of oil increases, and as newer methods of extracting the oil from the sands, such as those that employ compressed air, become more generally used, a larger percentage of oil will probably be taken from sands like the Shannon than has heretofore been taken, and the life of the pools in such sands will doubtless be considerably prolonged.

Teapot pool.—As the Teapot pool is almost entirely undeveloped, estimates of its oil content can best be made by comparing it with other pools. The known oil in this pool is found in the Shannon sand, which has yielded only small flows from wells in the Shannon pool but which, in the Big Muddy anticline near Casper, has furnished a considerable output of oil. The thickness of the lower oil-bearing ledge of the Shannon sand is recorded as 29 feet in a well in the NE. ¼ NW. ¼ sec. 10, T. 38 N., R. 78 W., and the oil obtained is said to be somewhat lighter in gravity than the oil from the Shannon pool. The oil is not under gas pressure, however, and the percentage that can be recovered from the sand is therefore less than that recovered from the Wall Creek sand. The Teapot pool is probably much smaller than the Salt Creek pool, but its limits can not be definitely outlined until more drilling is done. It may be tentatively assumed to be about half the size of the larger Salt Creek pool. The lower ledge of the Shannon sand is 29 feet thick, whereas the so-called "Lower Wall Creek" is probably about 25 feet. If we estimate that 25,000,000 barrels of oil can be recovered from the "Lower Wall Creek" in the Salt Creek pool, we should, because of difference in the gravity of the oil and lack of gas pressure in the Shannon sand, estimate that very much less oil—perhaps not more than 1,000,000 barrels—can be recovered from the Shannon sand than from the "Lower Wall Creek sand."

The possibility of obtaining oil from the Wall Creek sand on the Teapot fold has already been discussed (p. 35). As the conditions of accumulation there appear to be very similar to those in the Salt Creek dome and as the area is about half that of the Salt Creek pool, we can not do better than assume that the production from the Wall Creek sand in the Teapot dome may reach approximately half that from the same sand in the Salt Creek pool. A conservative estimate would be considerably less, perhaps 30,000,000 barrels.

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