DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

BULLETIN 641—F

OIL SHALE IN NORTHWESTERN COLORADO AND ADJACENT AREAS

BY

DEAN E. WINCHESTER

Contributions to economic geology, 1916, Part II
(Pages 139-198)

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OIL SHALE IN NORTHWESTERN COLORADO AND ADJACENT AREAS.

By DEAN E. WINCHESTER.

PREFATORY NOTE.

By MARIUS R. CAMPBELL.

For several years it has been known that some of the shale of the Green River formation in northwestern Colorado and northeastern Utah would produce oil when subjected to destructive distillation, but the yield of petroleum from the oil fields was so great that production by distillation did not seem to be feasible, despite the fact that in Scotland such an industry has long been developed and is to-day paying dividends on a large investment.

The United States Geological Survey has regarded this oil shale as a great reserve—an undeveloped resource—and one that would be developed as soon as the demand for petroleum greatly exceeded the supply. In anticipation of such an event, E. G. Woodruff and David T. Day began, in 1913, an examination of the Green River formation in Colorado and Utah and made rough field tests to determine the richness of the shale. Although these tests were not entirely satisfactory, they tended to confirm the general impression that this shale constitutes a source of oil which, sooner or later, will be called into use. Of course, no prediction could be made as to the date when this additional supply would be needed, but the Survey felt justified in continuing the geologic investigation, in order that when the time of need arrived it would have first-hand information on the richness and quantity of the shale available for distillation. Accordingly the field examination was continued during the summers of 1914 and 1915 by Dean E. Winchester, who devised a more efficient and portable apparatus for determining not only the quantity of crude oil in the shale but also the amount of gas and of ammonium sulphate (fertilizer) that might be obtained as a by-product and sold. The experiments of Mr. Winchester confirmed the results of the work done in the previous year and indicated even more strongly that a great quantity of high-class fuel is locked up in this shale.

At the present time, owing to the great increase in the consumption of gasoline and the failure to discover large new oil fields, it

seems that the day is approaching when this additional supply will be needed and that the public will demand all the information in the possession of the Geological Survey on this subject. I feel confident that this report of Mr. Winchester will supply many of the data needed to establish and develop the oil-shale industry in this country. The report contains information showing the quantity and quality of the oil that may be distilled from the richer beds of shale, the number of such beds at the different localities examined, and the general distribution of the shale throughout northwestern Colorado and adjacent parts of Utah and Wyoming. Mr. Winchester's results, which have been corroborated by tests made in the laboratory of the Bureau of Mines, show that the quantity of oil that can be derived from such shale ranges from less than 1 gallon to 90 gallons to the ton of shale. The field tests, however, were not intended to determine the best method of utilizing the shale in commercial operations, but simply to provide data for fixing approximately the value of the shale as it is found to-day. Mr. Winchester, as a result of the field tests, estimates that in Colorado alone there is enough shale to produce 20,000,000,000 barrels of oil, and it seems probable that in actual practice a greater yield than this can be obtained. He also estimates that 300,000,000 tons of ammonium sulphate could be recovered as a by-product in the manufacture of the oil.

The results given in this paper show that although the Geological Survey has done only reconnaissance work in this region, it has demonstrated that the shale of the Green River formation will yield a vast quantity of oil, gas sufficient to carry on the process of distillation, and fertilizer enough to enrich most of the farms of the Middle West, and that this reserve is ready whenever the demand is sufficient to warrant the establishment of a new industry to supplement the failing supply of petroleum from the oil fields.

INTRODUCTION.

The economic study of the oil shale of Colorado and Utah was begun in 1913 by Woodruff and Day,[1] and the results of their preliminary work showed that the shale of the Green River formation in Colorado and Utah will yield oil in commercial quantities when subjected to destructive distillation. As a result of a more detailed examination along the north, east, and southeast sides of the Uinta Basin, in northwestern Colorado, made during the summer of 1914 and in eastern Utah in 1915 the writer finds that although the thickest and richest beds of shale are exposed along the southern margin of the basin, nearly every section examined contains beds of shale more than 3 feet thick that will yield considerable oil. An examination of

[1] Woodruff, E. G., and Day, D. T., Oil shale of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 581, pp. 1-21, 1914 (Bull. 581-A).

the same formation in southwestern Wyoming in 1915 indicates that in that area there are no thick beds of rich shale.

The oil shale of the United States has received very little attention, chiefly because petroleum has been abundant. Before petroleum was discovered in Pennsylvania the Mormons distilled oil from shale near Juab, Utah, where the ruins of an old still can yet be seen. Many attempts have been made to distill cannel coal, and a few experiments have been made with the Devonian black shale of the East, but no shale-oil industry has been established in America. According to Baskerville [1] there were 55 oil companies in the United States in 1860. "Many of the companies were of small capacity and most of them were not more than fairly started when the discovery of petroleum paralyzed the industry." In Scotland, however, several well-established plants mine and distill shale of Carboniferous age. In 1908, according to Ells,[2] the oil-shale industry of Scotland employed about 8,300 men, of whom nearly 4,000 were miners; and in the preceding year the production of oil shale in Scotland amounted to 2,775,799 (long) tons, and the average yield of crude oil was 23 (Imperial) gallons to the long ton (24.6 United States gallons to the short ton).[3] The operations have paid dividends in spite of this low yield, because of the cheapness of labor, the value of the by-products, and lack of competition with petroleum. The cost of mining shale in Scotland is reported by the same author to be $1 a ton, the cost of distilling the crude oil from the shale is 40 cents a ton, and the cost of making ammonium sulphate (the principal by-product) from the shale is 46 cents a ton. All mining in Scotland is underground, and in many of the mines the shale beds dip at angles of 30° to 60° and there are numerous faults, which greatly increase the expense of mining. At many places in Colorado and Utah, however, the rich shale has only a light overburden (see Pl. XI) and could be mined with a steam shovel.

In Colorado alone there is sufficient shale, in beds that are 3 feet or more thick and capable of yielding more oil than the average shale now mined in Scotland, to yield about 20,000,000,000 barrels of crude oil, from which 2,000,000,000 barrels of gasoline may be extracted by ordinary methods of refining, and in Utah there is probably an equal amount of shale just as rich. The same shale in Colorado, in addition to the oil, should produce with but little added cost about 300,000,000

[1] Baskerville, Charles, Economic possibilities of American oil shales: Eng. and Min. Jour., vol. 88, pp. 149–154, 195–199, 1909.

[2] Ells, R. W., Report on tests made in Scotland of oil shale sent from New Brunswick in the spring of 1908, with a view of ascertaining its economic value, especially as regards the yield of crude oil and sulphate of ammonia, pp. 24, 26, Canada Dept. Mines, 1910.

[3] In this paper results of distillation are given in United States gallons (42 gallons to the barrel) and referred to the short ton (2,000 pounds). Care should be taken in comparing figures with those given in reports on oil shale of Scotland, in which results are given in Imperial gallons (35 gallons to the barrel) and referred to the long ton (2,240 pounds).

tons of ammonium sulphate, a compound especially valuable as a fertilizer. The industry requires a large equipment of retorts, condensers, and oil refineries, as well as of mining machinery, so that it can not be profitably handled on a small scale.

In Scotland, according to Ells,[1] the following valuable products are manufactured from the shale: (1) permanent gas, used principally for fuel in the retorts; (2) naphtha, gasoline, and motor spirit; (3) burning or lamp oil; (4) intermediate oil used for gas making; (5) lubricating oil; (6) solid paraffin; (7) still grease; (8) still coke, which contains some oil and is used for gas fires, smokeless fuel, and carbon for electrical purposes; (9) sulphate of ammonia [a fertilizer which in the United States is worth from $50 to $60 a ton]; and (10) liquid fuel, used in the refineries. The distillation of the oil shale of the Green River formation will probably yield different products, and the processes of distillation used in Scotland may not be well adapted to this shale.

In the 11 field tests made by Woodruff[2] in 1913, 1 sample of shale yielded as low as 10.4 gallons of oil to the ton of shale; 8 between 16 and 40 gallons, averaging 27.2 gallons; one 45.2 gallons; and one 61.2 gallons. Of the 57 samples tested in 1914 (Nos. 1–57, pp. 152–153), 17 samples yielded less than 10 gallons of oil to the ton of shale; 22 samples between 10 and 20 gallons; 11 samples between 20 and 30 gallons; 3 samples between 30 and 40 gallons; 2 samples 40.6 gallons each; 1 sample 65.3 gallons; and 1 sample 86.8 gallons. Seventy-five samples (Nos. 58–133) were tested in 1915. Of those obtained in Utah (34 samples, Nos. 58–91) 6 yielded less than 10 gallons of oil to the ton of shale; 7 between 10 and 20 gallons; 7 between 20 and 30 gallons; 9 between 30 and 40 gallons; and 5 more than 40 gallons. The maximum yield, 90 gallons to the ton, was obtained from a thin bed near Watson, Utah. Samples 93–132, from Wyoming, yielded less than 30 gallons, except 4, which yielded more than 30 gallons. One of these represented a 2-foot bed, which yielded 50 gallons to the ton.

As these quantities compare favorably with those obtained from the oil shale of Scotland, it seems probable that in time the distillation of oil from the Green River shale may become as important an industry in this country as the distillation of oil from Carboniferous shale has become in Scotland, or if richer raw material can be found here in abundance it may even exceed the present shale-oil industry abroad.

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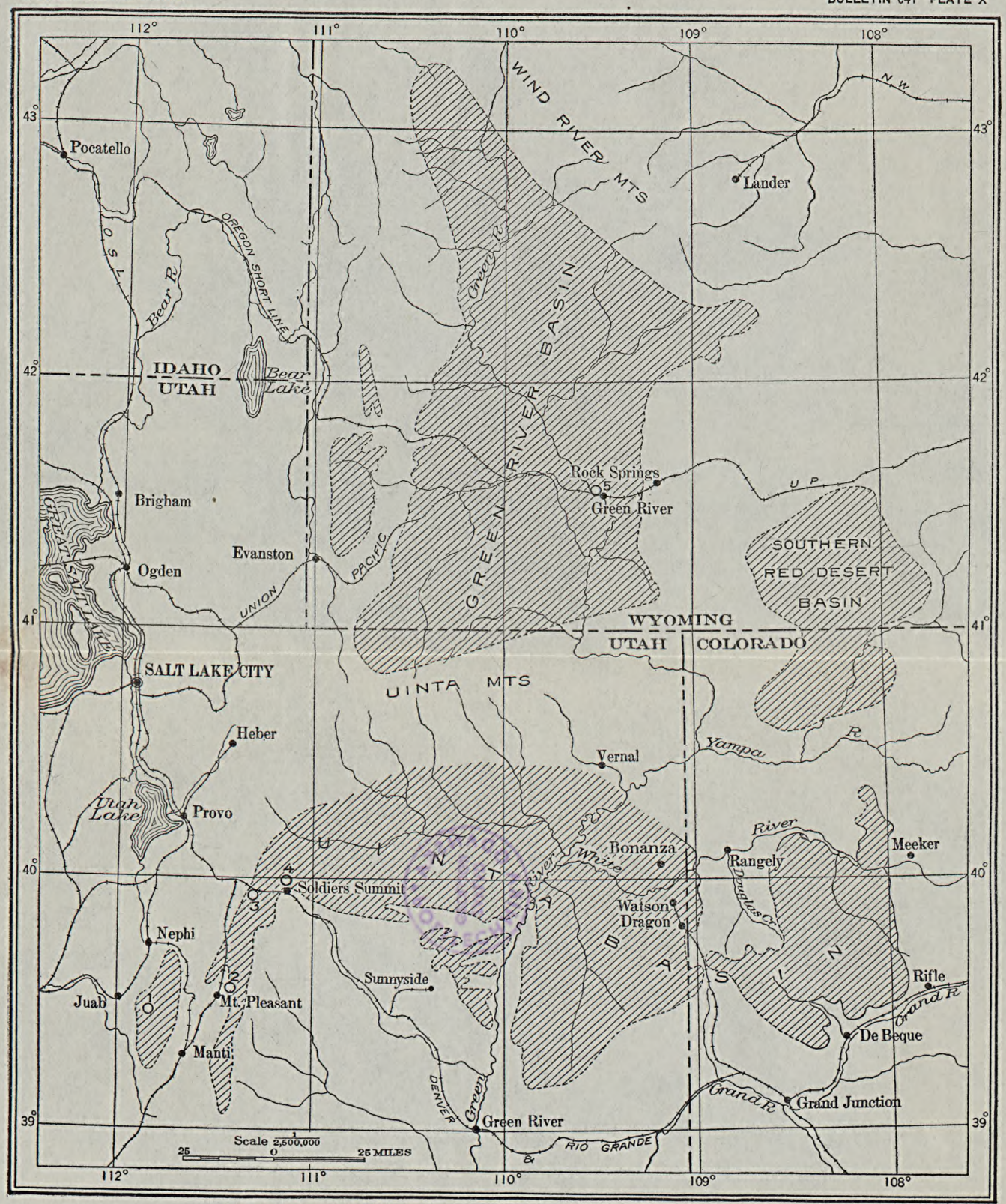
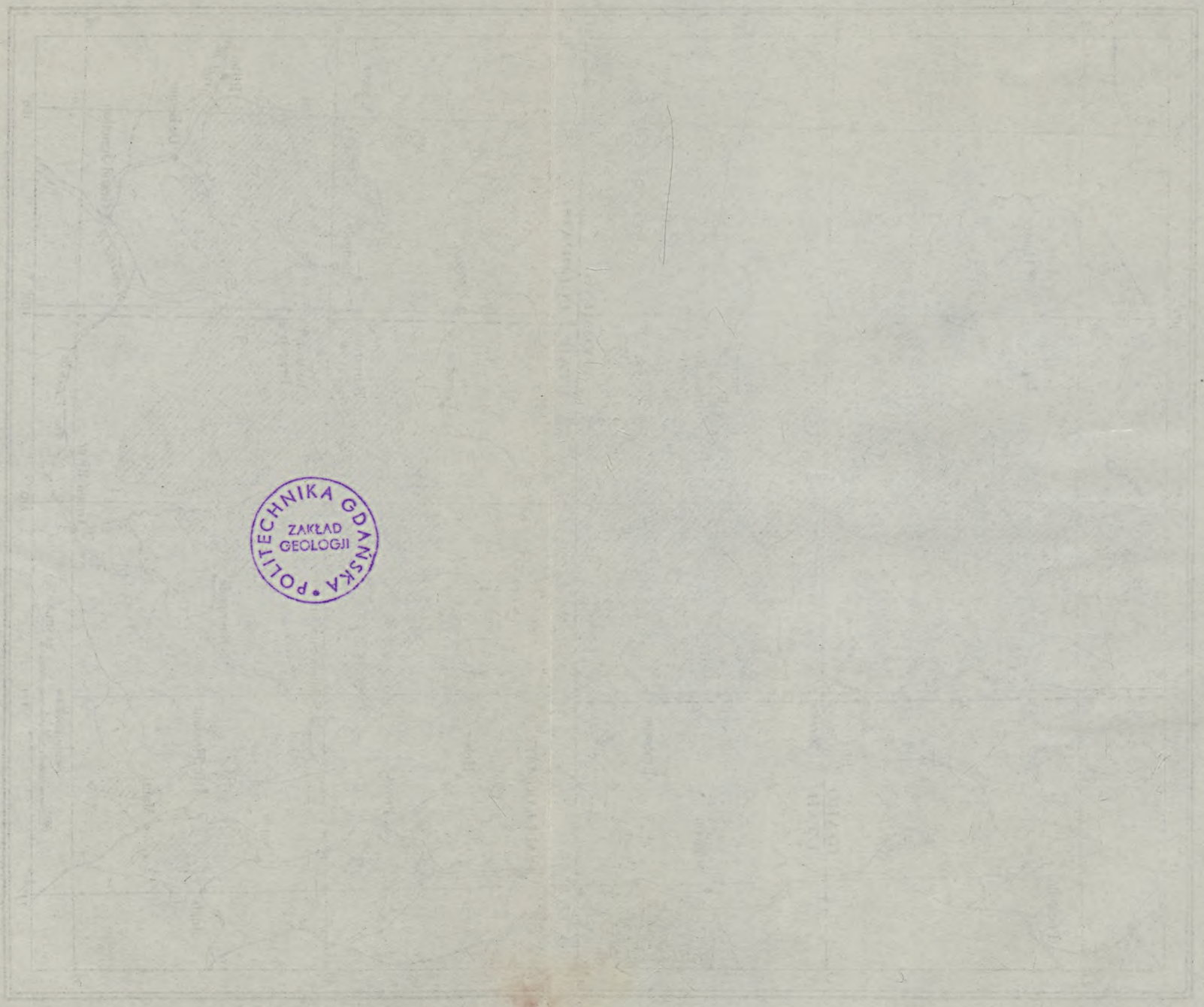
[1] Ells, R. W., op. cit., pp. 54–56.

[2] Woodruff, E. G., and Day, D. T., op. cit., p. 4.



KEY MAP OF NORTHWESTERN COLORADO AND ADJACENT AREAS.



FIELD WORK.

Personnel and methods.—In order to estimate the value of the oil shale of the Green River formation as an economic resource, the writer, assisted by H. M. Robinson and Frank A. Elliott, in 1914, made a careful study of the entire exposed portion of the formation at a number of places along the north, east, and southeast sides of the Uinta Basin in Colorado (localities A to P, Pl. XVIII). During the later part of the season Mr. Robinson made a hasty examination of the shale of the same formation at several places in northeastern Utah (localities 1–4, Pl. X). During the season of 1915 Walter B. Wilson, John N. Massey, and Yong K. Lee assisted the writer in examining the southern part of the area of the Green River formation in southwestern Wyoming and the south side of the Uinta Basin, near the eastern line of Utah. A large number of samples of shale were distilled in the field and in the laboratory of the Bureau of Mines at Washington to determine the quantity of oil and other products which could be obtained from them. Much of the chemical work was done under the direction of David T. Day, of the Bureau of Mines. C. A. Davis, also of the Bureau of Mines, was detailed to the Survey for several months to make a microscopic study of the organic matter in the shale. To Messrs. Day, Davis, and David White, who visited the field early in September, 1914, the writer is indebted for many helpful suggestions concerning methods of work and interpretation of results.

The limits of the Green River formation were mapped in the field and the exact place at which each sample of shale was obtained was determined by the use of telescopic alidade, stadia rod, and plane table. Geologic sections were measured at several localities. The accompanying map of northwestern Colorado and eastern Utah (Pl. XVIII) is compiled from field sheets prepared by the writer, from published and unpublished data collected by Gale [1] in connection with an examination of coal fields in the adjacent areas, and from data shown on the township plats of the General Land Office. The land net was compiled from these plats, but owing to discrepancies between surveys and resurveys it was necessary to make numerous more or less arbitrary adjustments and the land net shown on the map therefore comprises only township lines. The resurvey of the area north of the base line in Colorado and along Douglas Creek south of it was only recently completed, and the corners are well marked, but the corner posts of the much older surveys elsewhere are very poorly preserved or entirely gone. The land survey of that part of eastern Utah shown on Plate XVIII is good. In many places the geologic boundaries shown are taken directly from maps published

[1] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, 1910.

by Mr. Gale, inasmuch as wherever tested these maps proved to be entirely satisfactory for the purposes of this work. The places from which samples 1–4 were collected are shown on the smaller map (Pl. X).

The map of southwestern Wyoming (Pl. XIX) is compiled from maps by Veatch[1] and Schultz[2] and unpublished data by Schultz, together with the data collected by the writer during the field work and data shown on the township plats of the General Land Office. A large part of the area has been recently resurveyed, and the land lines are trustworthy, except in the extreme eastern part, where the old survey is known to be very poor.

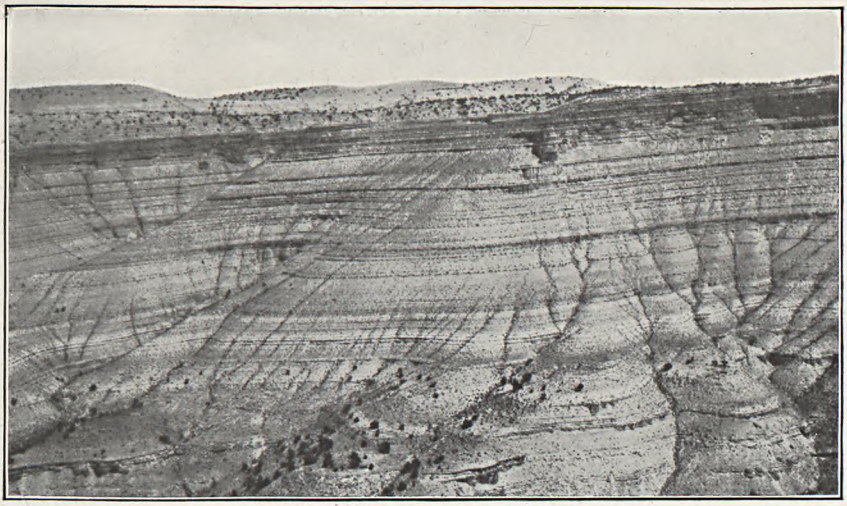
Area examined.—The examination of 1914 was confined to a narrow strip about the north, east, and southeast sides of the Uinta Basin in Colorado, except that during a short trip into central Utah Mr. Robinson sampled shale beds at the four localities shown on Plate X. A portion of the outcrop of the formation along the Colorado-Utah line near White River was examined, but the greater part of the season was spent along the margin of the main basin to the east. The Green River formation occupies an area of about 1,900 square miles in Colorado and a larger area in northeastern Utah. The main area in Colorado is separated from the Utah part of the Uinta Basin by the Douglas Creek anticline, which extends in a general northerly direction along the valley of Douglas Creek near the State line. The limit of the oil-yielding shale in most places practically coincides with the boundary of the Green River formation, but northwest of Meeker only the lower part of the formation is present, and this is barren of oil. A similar condition prevails south of Grand River.

The eastern edge of the Uinta Basin in Utah, near Watson, was examined in considerable detail during August and September, 1915. Most of the season, however, was spent in a reconnaissance examination of southwestern Wyoming (Pl. XIX). The eastern margin of the Green River formation in Wyoming between the Union Pacific Railroad and the Colorado-Utah-Wyoming line was examined, and samples of shale from the localities indicated on the map were tested. A hurried trip was made across the Green River basin to Fossil, Wyo., and southward along the western part of the area known to contain the Green River formation.

Northwestern Colorado and northeastern Utah.—The surface of the part of the field represented by Plate XVIII consists mainly of deeply dissected uplands surrounded on all sides by more open valleys carved in the shale and soft sandstone of the Wasatch formation,

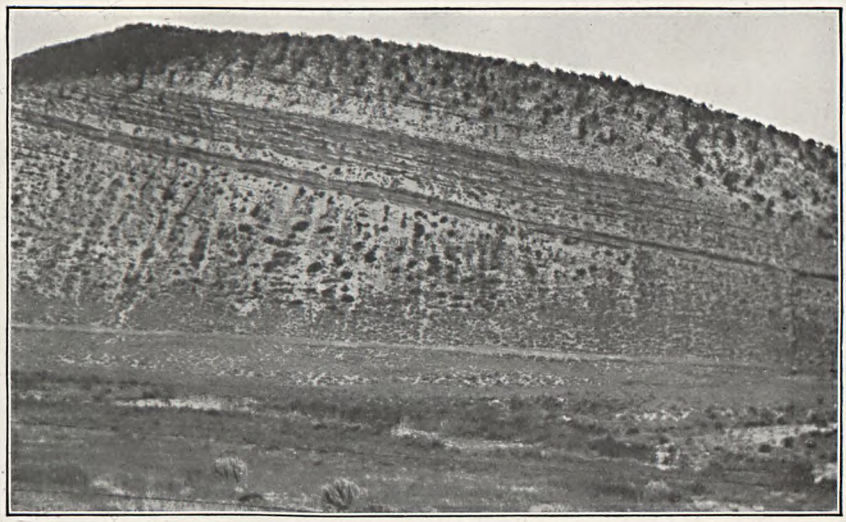
[1] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: U. S. Geol. Survey Prof. Paper 56, pl. 3, 1907.

[2] Schultz, A. R., The southern part of the Rock Springs coal field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 381, pp. 214–281, 1908.



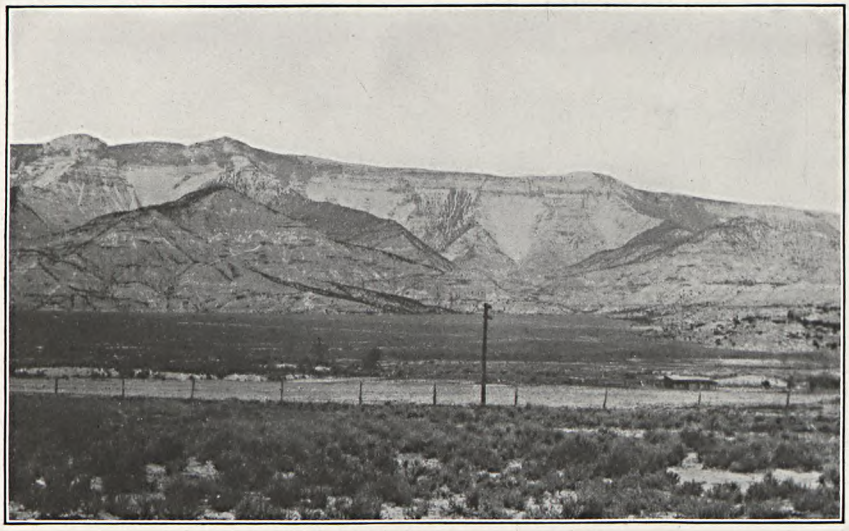
A. OIL SHALE NORTHEAST OF WATSON, UTAH.

Shows thin bedding in this part of the Green River formation. Darker bands are richest beds. About 600 feet of rock exposed.



B. OIL SHALE ON EAST SIDE OF PICEANCE CREEK NEAR WHITE RIVER, COLO.

Most of the projecting ledges are rich shale.



A. BOOK CLIFFS WEST OF RIFLE, COLO.

Oil shale forms upper cliff. About 3,000 feet of rock exposed. (See fig. 13, p. 145.)

B. GREEN RIVER FORMATION NORTH OF WHITE RIVER, 9 MILES WEST OF RANGELY, COLO.

Dark projecting beds are oil shale. Cliff about 1,000 feet high.

which lies beneath the oil-yielding Green River shale and above the coal-bearing Mesaverde formation. The Book Cliffs near Rifle, Colo. (Pl. XII, *A*), stand about 9,000 feet above sea level. The Grand Hogback, which extends along the eastern margin of the field nearly parallel with the boundary of the Green River formation, reaches an altitude of about 9,500 feet and is formed by the steeply upturned resistant sandstones of the Mesaverde formation. The Green River formation, probably owing to the presence of oil-yielding shale, resists erosion to a marked degree and gives rise along the southern margin of the area to nearly perpendicular and at most places impassable cliffs, which in the vicinity of Rifle and De Beque rise to heights of 3,000 or 4,000 feet above the valley of Grand River, only a few miles distant. (See fig. 13.) West of the Grand Hogback and north of Rio Blanco post office the shale forms hills of considerable prominence, known as the Petrolite Hills. The outcrop of

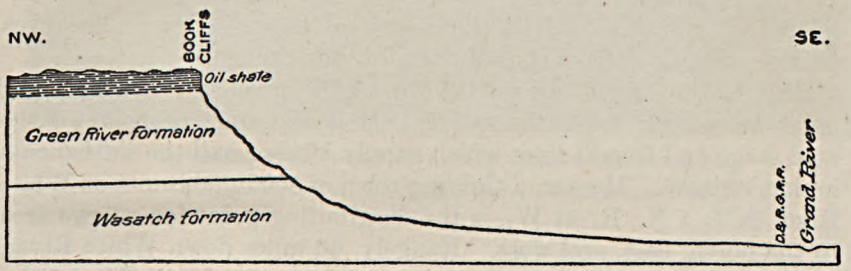


FIGURE 13.—Section from Grand River near Rulison, Colo., to the Book Cliffs on the north, showing the position of the oil shale.

the oil shale along the east side of the Douglas Creek anticline is marked by nearly perpendicular cliffs known as the Cathedral Bluffs. Cliffs similar to these and equally impassable form the boundary of the formation along White River (Pl. XII, *B*) and southward along the Colorado-Utah State line to a point near Watson, Utah. (See Pl. XI, *A*.)

By far the larger part of this area drains northward to White River through Evacuation, Douglas, Yellow, and Piceance creeks, and to the Pacific Ocean through Green and Colorado rivers. That part of the area south of the Book Cliffs is drained by Grand River, which joins Colorado River in Central Utah. White and Grand rivers and Roan, Douglas, Yellow, and Piceance creeks are the only streams that carry water throughout the year.

The valley of Grand River is traversed by the main line of the Denver & Rio Grande Railroad. The narrow-gage line of the Uintah Railway between Mack, Colo., and Watson, Utah, crosses the Book Cliffs near the Colorado-Utah line and furnishes transportation facilities for a considerable part of the Uinta Basin. The

ranchers and farmers in this area do a very large part of their shipping by way of Meeker, Rifle, and the Denver & Rio Grande Railroad. The proposed extension of the Denver & Salt Lake Railroad ("Moffat road") westward from Craig down Yampa River, to the north of the field, will furnish an additional outlet.

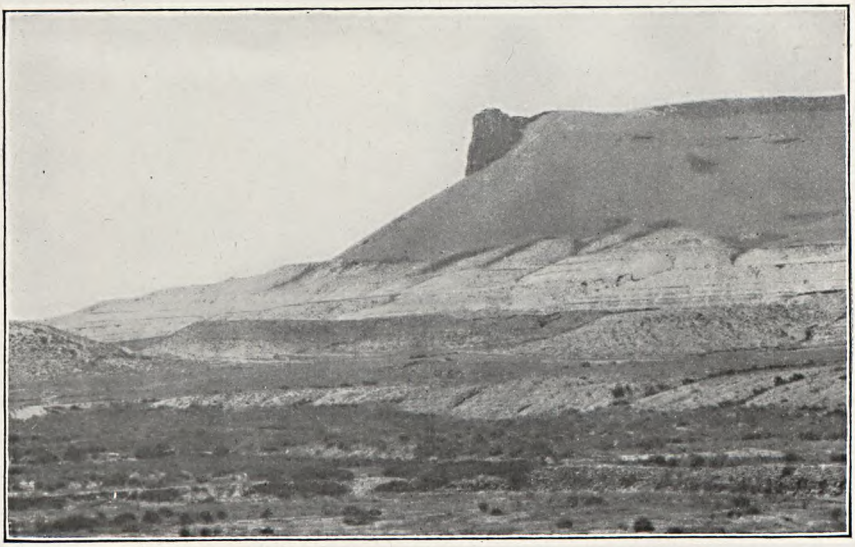
The surface of the area is so rough that wagon travel is forced to follow certain long-used routes, such as the Government road from Rifle to Meeker and the well-kept road between Meeker and Rangely down the valley of White River. Roads also lead from Rangely northwest and southwest to Vernal and Dragon, Utah, respectively, and there is a fair wagon road up Piceance Creek connecting with the Government road at Rio Blanco post office. Aside from these wagon roads there are few routes that can be used to advantage.

The valleys of White and Grand rivers and of Piceance and Roan creeks are occupied by small but prosperous ranches which under irrigation produce alfalfa, timothy, grain, and vegetables. Considerable fruit is raised in the valley of Grand River. The area outside of these valleys is used only for stock range.

Rifle is the largest railroad town in the area and is a shipping point for nearly the entire region. It is the starting point of the mail stage and freight lines which supply Meeker and the settlements in that vicinity. Meeker, a thriving town of 800 inhabitants on White River in T. 1 N., R. 94 W., is the distributing point for a large area to the north, east, and west. Rangely, 60 miles down White River, consists of a store and post office and is connected with Meeker by stage that makes three trips a week. Supplies for Rangely and vicinity are freighted from Dragon, Utah, a station on the Uintah Railway, and Watson, at the end of the same railway 9 miles north of Dragon, is the shipping point for ore from the gilsonite mines of the Uinta Basin and for produce from Ashley Valley, 50 miles to the northwest. A toll road from Watson to Vernal is used by daily automobile mail and passenger stages that connect with the trains of the Uintah Railway. Rio Blanco, halfway between Rifle and Meeker, consists of a small store and post office. Piceance and Sulphur are merely post offices located at ranch houses. De Beque and Grand Valley are small but prosperous towns on the Denver & Rio Grande Railroad south of the Book Cliffs.

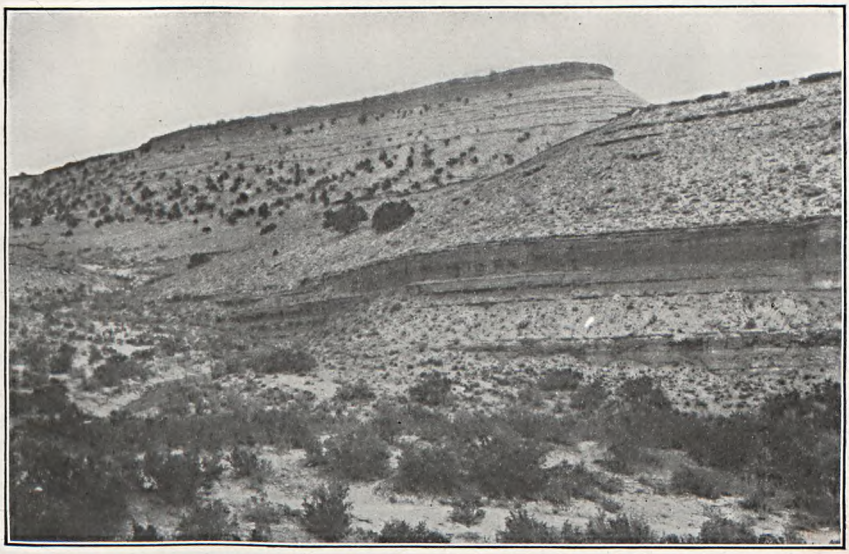
Southwestern Wyoming.—That portion of southwestern Wyoming which is shown on the map (Pl. XIX) includes the southern part of the Green River basin and the western rim of the Southern Red Desert Basin. The surface is in most places rolling and covered with vegetation characteristic of arid regions.

Trees grow only along streams and in a few small upland areas. The region is drained through Green River and its tributaries except in the area adjacent to the west line of the State, where the run-off

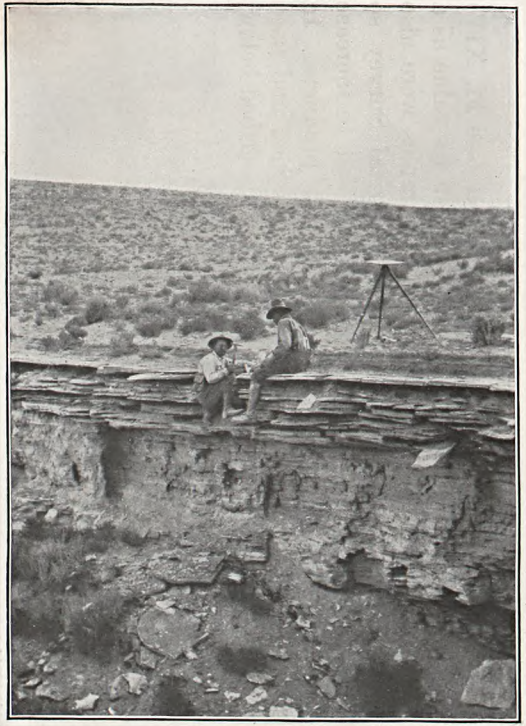


A. GREEN RIVER FORMATION EAST OF GREEN RIVER CITY, WYO.

Samples of oil shale 127 and 128 taken from beds at base of upper cliff.

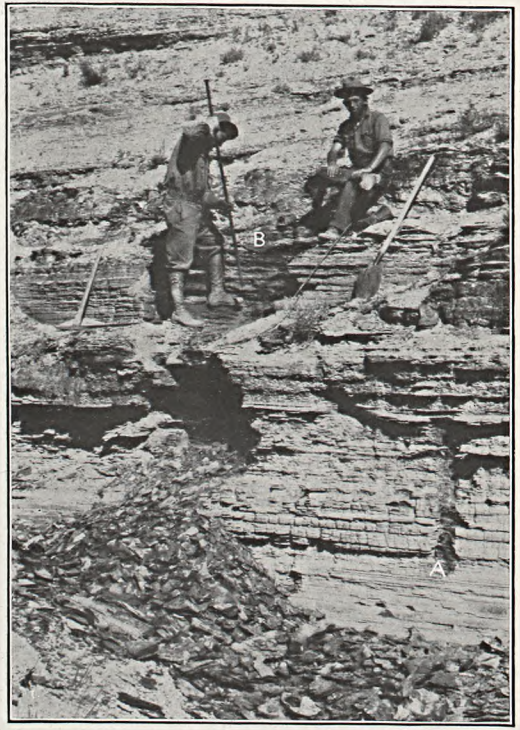


B. GREEN RIVER FORMATION IN T. 10 S., R. 15 E., ABOUT 25 MILES NORTH OF SUNNYSIDE, UTAH.



A. SAMPLING BED OF OIL SHALE SOUTH OF GREEN RIVER CITY, WYO.

Shows characteristic weathering of bed containing alternating rich and poor seams The richer seams are more resistant.



B. SAMPLING BED OF OIL SHALE NEAR WATSON, UTAH.

A, Narrow channel in weathered face, from which sample 65 was taken. B, Larger cut in same bed, from which sample 66 was taken.

finds its way to Great Salt Lake by the way of Bear River. Steep cliffs mark the eastern margin of the main basin, and Green River valley is bordered by precipitous walls for several miles near the town of Green River. (See Pl. XIII, *A*.) Altitudes range from 5,900 feet above sea level on Green River near Linwood to 8,750 feet in the southwestern part of the area shown on the map.

Green River has its beginning far to the north, in the Wind River Mountains, but its principal tributaries in this area, Blacks Fork and Henrys Fork, rise in the Uinta Mountains of northern Utah. Aside from the three streams mentioned above, together with Hams Fork, a tributary of Blacks Fork, and Bear River, there are in this area very few streams that carry water the year round.

The main line of the Union Pacific Railroad crosses the area in a general westerly direction and is joined at Granger by the Oregon Short Line, which connects with points to the northwest. Rock Springs, Kemmerer, and Evanston, coal-mining towns, and Green River, a railroad division point, are the principal towns of the region. Several villages have been established in the irrigated district around old Fort Bridger and along Henrys Fork near the southern line of the State. Many of the towns on the railroad consist of only a few houses, a store, and a post office. The Lincoln Highway follows in general the line of the Union Pacific Railroad, and good automobile roads connect many of the smaller towns with the railroad and this highway.

TESTS OF THE SHALE.

APPARATUS FOR FIELD DISTILLATION.

A large number of samples of shale were collected (see Pl. XIV) and tested in the field in order that a definite idea of its value as a source of oil might be obtained. Several large samples were also shipped to the chemical laboratory of the Geological Survey so that different methods of treatment might be devised to increase if possible the yield of crude oil and other valuable products. In the early part of the work (1914) the apparatus designed and used by Woodruff and Day [1] during the previous season, described below, was used to make the tests.

The retort into which the shale was charged consisted of a section of 12-inch iron casing pipe 4 feet long, having flanges screwed on the ends and a removable iron plate with asbestos gaskets fitted to each end of the retort. On one side of the retort there was fitted a small steam dome, a pressure gage, and a safety valve. From the top of the dome a pipe led to a block-tin condensing coil in a small water-filled tank. The coil discharged into Wolff bottles set in series and provided with stopcocks so that the liquids could be drawn off without interfering with the operation of the condenser. During the operation the retort was suspended from iron supports in a narrow trench,

[1] Woodruff, E. G., and Day, D. T., op. cit., p. 4.

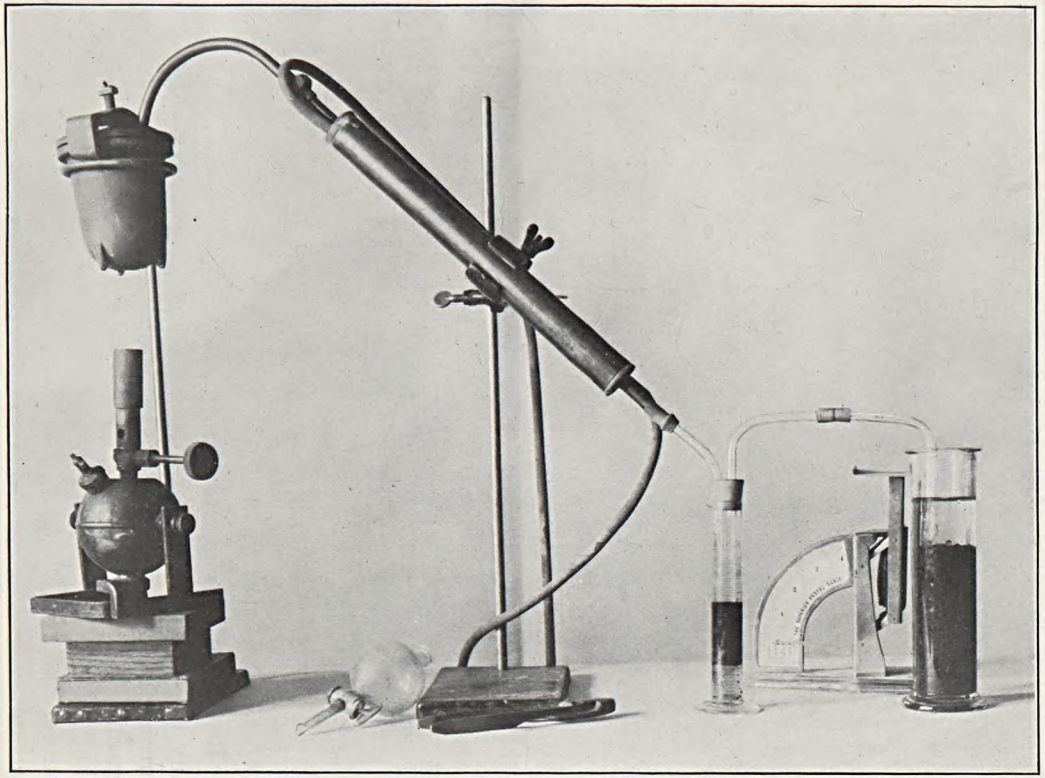
covered with iron plates and earth, and a flue erected at the back. Heat was obtained from a wood fire placed under the retort.

The operation consisted of removing the head, charging the retort with shale broken into pieces not larger than 4 inches in diameter, and replacing the head. Fire was started to give a gentle heat at first and was gradually increased until the lower part of the retort became red hot; then the fire was held constant until near the close of the process, when it was increased for a short time and then allowed to subside. Water vapor, gas, oil and gas, and finally only gas was the order in which the products were obtained. From seven to eight hours' heating was required for a charge.

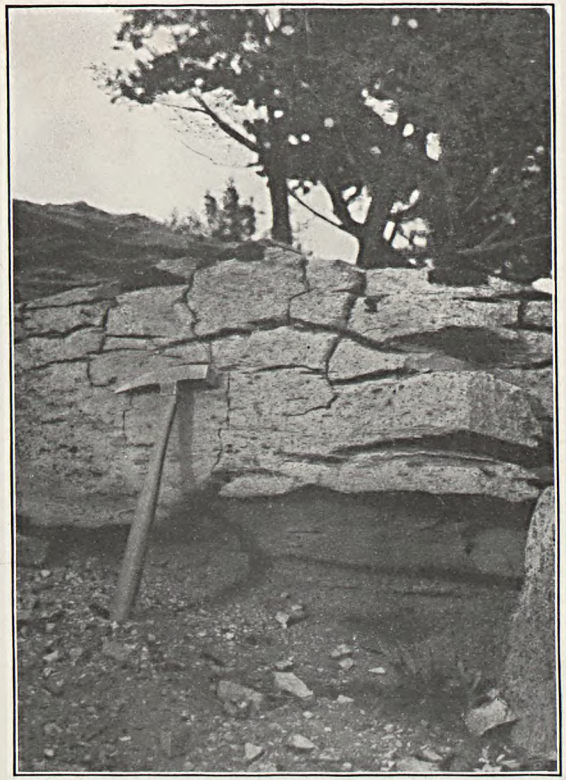
This apparatus necessitated the mining of a large quantity of shale (100 pounds or more) for each test. The apparatus, being large and not easily transported and eventually becoming unfit for use through leakage, was abandoned and replaced by a small still which required a sample weighing only about 1 pound and which was heated by gasoline torches. With two of these small distilling outfits four samples of shale were tested easily in one working day, whereas only one sample of shale a day could be tested with the larger apparatus. The distilling apparatus used in 1915 (see Pl. XV), which is similar to that used during the later part of the 1914 season, but much more compact and lighter, consists of the following essential parts:

Two gasoline blast lamps (Barthel's).
One iron mercury retort (one-half pint) with delivery tubes.
One brass condenser.
Two ring stands.
One 3½-inch ring.
One large condenser clamp.
One receiver for condensed liquids (50 cubic centimeter glass graduate).
One ammonia scrubber (8-ounce bottle filled with glass beads).
Two pairs combination pliers.
One postal balance.
Six feet of rubber tubing.
Glass tube for connecting condenser, receiver, and ammonia scrubber.
One glass separatory funnel.

Because of its simplicity and because its flame can be adjusted to any desired angle or length, the Barthel blast lamp was chosen to furnish heat for the still. This lamp consists of a small spherical gasoline tank with burner, mounted on an iron base in such a way that the burner may be turned at any angle. To manipulate the burner the tank is first filled nearly full of gasoline and the cap securely screwed down. Gasoline is placed in the small cuplike depression around the burner and lighted. When this gasoline is burned out, sufficient heat will have been produced to generate gas under pressure, which may be lighted at the end of the burner on opening the burner valve. If the flame is yellow or sputters the burner is not sufficiently hot and must be reheated. The gasoline tank of each burner holds sufficient fuel to keep the blast burning about 2 hours. Inasmuch as each distillation of shale requires from

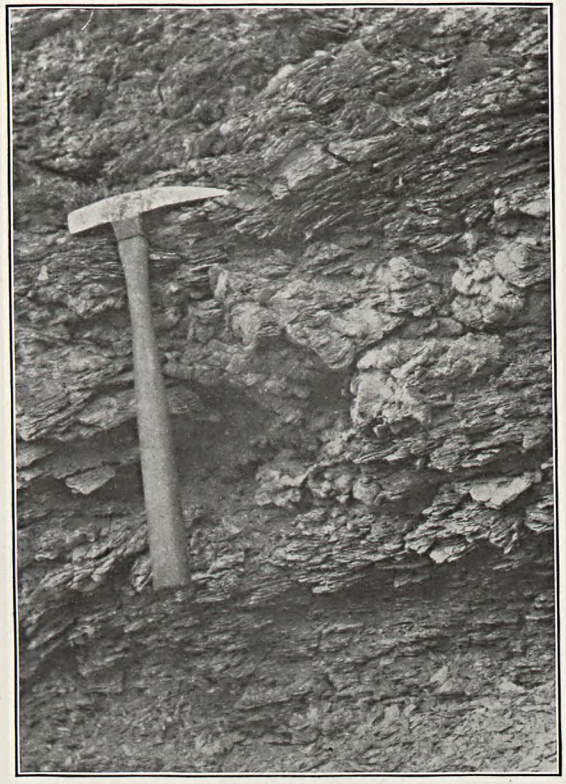


FIELD APPARATUS FOR DISTILLING OIL SHALE.



A. CHARACTERISTIC WEATHERING OF RICH, MASSIVE OIL SHALE.

Near Welch ranch, T. 1 N., R. 100 W., Colorado.



B. CHARACTERISTIC WEATHERING OF OIL-YIELDING PAPER SHALE.

West side of Piceance Creek near White River, Colo.

3 to 4 hours, two burners are used with each retort. The second torch may be most easily lighted by playing the flame of the first on the burner of the second.

The vessel in which the shale is placed to be heated is an ordinary iron mercury retort (capacity, one-half pint), which is equipped with close-fitting lid and clamp and an iron delivery tube. The delivery tube is fastened to the inner tube of the condenser by a small brass plumber's union, which provides a very easily disconnected joint. The retort is held in place above the flame of the burner by a ring and ring stand.

The condenser used in the outfit consists of an inner tube of thin brass three-eighths of an inch in diameter and 15 inches long, to one end of which is soldered a small brass plumber's union. This inner tube is surrounded by a second thin-walled brass tube 1¼ inches in diameter, 11 inches long, which is provided with a two-hole rubber stopper at each end, one hole being for the inner tube. A small brass tube 2 inches long is inserted through the second hole of each stopper to provide connection for the entrance and waste of the water which is circulated between the inner and outer tubes to keep the inner tube cool. The delivery tube from the retort is so bent that when the retort is in an upright position the condenser will be turned at an angle of about 40° from the horizontal. The condenser is held in position by a single clamp, attached to a ring stand.

The receiver for the condensable products of the distillation consists of a 50 cubic centimeter glass graduate, provided with a two-hole rubber stopper through which are thrust two glass tubes, one for the entrance of the liquids and permanent gases from the condenser and the other for the escape of the permanent gases to the ammonia scrubber. The glass tubes have a diameter of about a quarter of an inch and are bent at the proper angles to make connections with the condenser and scrubber. The tubes should barely penetrate the cork.

The ammonia scrubber consists of an ordinary glass cylinder or 8-ounce wide-mouthed bottle, provided with a glass tube reaching nearly to the bottom of the bottle for the entrance of permanent gas from the receiver. The bottle is filled with glass beads, which provide additional surface and a means of breaking up the gas into small bubbles as it passes up through a 10 per cent solution of sulphuric acid.

The water for cooling the condenser may be had from waterworks, or if no running water is at hand a tank or tub may be stationed near the condenser, at a slightly higher level, and the water conveyed over the top by a siphon entering the condenser at the lower end and wasting at the upper end.

The pliers are used for handling the retort.

The postal balance has a capacity of 4 pounds and is used to weigh the sample of shale.

The glass separatory funnel is used to separate the oil from the water derived from the shale.

In order to determine the quantity of oil and ammonia that may be derived from a sample of shale, the shale is first pulverized to pass through a screen of ½-inch mesh. After thorough mixing a sample weighing 8½ ounces is so selected as to represent the entire quantity. This sample is placed in the iron retort and the cover securely fastened. In order to prevent leaks the joint between the cover and retort bowl is plastered with a thick paste made of a mixture of powdered graphite and glycerine. The delivery tube from the retort is then coupled with the inner tube of the condenser. The ammonia scrubber is filled approximately two-thirds full with a 15 per cent solution of sulphuric acid, and cool water (not ice water) is started circulating through the condenser. The blast lamp is then lighted and placed beneath the retort, with the flame turned as low as possible. After heating about 10 minutes water and oil will begin to condense and be delivered into the receiver. The permanent gas will pass into the ammonia scrubber and bubble up through the sulphuric acid, which will combine with any ammonia contained in it, producing soluble ammonium sulphate. Gentle heat should be applied to the retort as long as any oil is delivered to the receiver; then the flame of the burner may be lengthened until at the end of three or four hours the burner will be at full blast, the retort will be red hot, and the shale will cease to yield either oil or gas. The products of the distillation are then measured; the quantity of oil in the receiver is recorded, as well as the quantity of water in the same receiver. The liquid products of the distillation are then transferred to the separatory funnel and the water drawn off from the oil and added to the liquid contained in the ammonia scrubber. The material contained in the ammonia scrubber is then placed in a glass-stoppered bottle and transferred to a chemical laboratory for the determination of the quantity of ammonium sulphate. The yield of oil in United States gallons to the short ton of shale is equal to the number of cubic centimeters of oil in the receiver, provided the sample of shale used weighs 8½ ounces. The oil obtained from the distillation should be placed in a small bottle for determination of its specific gravity, which can best be done in the laboratory. In order to compute the number of pounds of ammonium sulphate which may be derived from a short ton of shale it is necessary only to multiply the number of grams of ammonium sulphate found in the sample by 8.8.

RESULTS OF TESTS.

SALIENT FEATURES.

The results of the tests made in the field and in the laboratory at Washington are given below and show variation from a maximum yield of 90 gallons of oil to the ton of shale to a minimum of 0.31 gallon. The yield of ammonium sulphate was not determined for samples tested during the early part of the first season's work, but those which were tested show a range from 18.3 pounds by dry distillation or 34 pounds by steam distillation to 0.4 pound to the ton of shale. Likewise the yield of inflammable gas ranges in the samples for which the amount was recorded from 4,549 cubic feet to the ton of shale to less than 500 cubic feet. Many of the samples that were subjected to destructive distillation were selected not because they were supposed to be rich in oil but in order that the field men might be better able to judge from the appearance of the shale how much oil it would yield when subjected to distillation. Several samples were selected in order to determine the geologic range of oil-yielding shale. All samples were taken near the outcrop, and it is probable that some of the more volatile constituents of the oil had been lost by evaporation, hence the results of distillation tests do not show the maximum amount of oil that may be obtained even by the method of distillation used. The stratigraphic position of nearly all the beds sampled is given in the sections (pp. 170–189).

Results of distillation of samples of oil shale collected in 1914.

Sample No.	Location. Sec.	T.	R. W.	Thickness of shale sampled.	Weight of shale used.	Crude oil obtained (cubic centimeters). Dry.	With steam.	Equivalent yield of oil per short ton of shale (United States gallons).	Gravity of oil at 60° F. Specific gravity	Degrees Baumé.	Yield of gas per short ton of shale (cubic feet).	Yield of ammonium sulphate per short ton of shale (pounds).	Remarks.
				Ft. in.									
1	Juab, Utah			2 9	6 ounces.	8.5		11.9	0.8995	25.6	1,198	2.5	Laboratory test.
2	Mt. Pleasant, Utah				6 ounces.	8.5		11.9	.8866	27.9	3,352	2.2	Do.
3	Tucker, Utah			3 0	6 ounces.	8.5		11.9	.8965	26.2	2,525	6.5	Do.
4	Soldiers Summit, Utah.			6 3	6 ounces.	12.0		16.8	.8937	26.6	2,864	3.5	Do.
5	Green River, Wyo.[a]				6 ounces.	21.0		29.4	.9130	23.3	2,978	9.0	Do.
6	Elko, Nev.[b]				6 ounces.	62.0		86.8	.8850	28.2	3,891	6.0	Do.
7	9	1 N.	103	2 ½	85 lbs.	2,040.0		12.6+	.9235	21.6			Field test; retort leaked.
8	9	1 N.	103	4 8	117 lbs.	946.2		4.26	.9371	19.4			Field test.
9	9	1 N.	103	3 10	6 ounces.	8.5		11.9	.9010	25.4	2,395	7.1	Laboratory test.
10	9	1 N.	103	3 10	104 lbs.	2,217.7		11.3	.9138	23.2			Field test.
11	9	1 N.	103	1 11	130 lbs.	2,040.3		8.22					Field test; retort leaked.
12	9	1 N.	103	2 3	150 lbs.		2,454.3	8.64	.9290	20.7			Field test.
13	26	1 N.	100	5 0	6 ounces.	24.0		33.6	.8919	27.0	3,034	9.7	Laboratory test.
14	15	2 N.	98	5	6 ounces.	9.5		13.3	.9165	22.7	3,034	12.8	Do.
15	15	2 N.	98	1 2	1 lb.	7.4		3.0					Field test; retort leaked.
16	15	2 N.	98	1 4	1 lb.	3.7		1.9					Field test.
17	15	2 N.	98	6	6 ounces.	15.0		21.0	.9059	24.8	3,123	18.2	Laboratory test.
18	16	2 N.	98	3 4	142 lbs.		6,150.6	22.88	.9290	20.7			Field test.
19	16	2 N.	98	3 4	142 lbs.	1,685.5		6.27	.9327	20.0			Do.
20	10	2 N.	98	3 0	6 ounces.	9.0		12.6	.9030	25.0	3,512	16.4	Laboratory test.
21	10	2 N.	98	4 6	115 lbs.	1,685.5		26.8					Field test.
22	15	2 N.	98	3 5¾	6 ounces.	11.0		15.4	.9310	20.4	3,592	9.0	Laboratory test.
23	15	2 N.	98	2 2	150 lbs.	2,158.6		7.61	.9321	20.2			Field test.
24	14	2 N.	98	1 6	135 lbs.		1,537.6	6.25+	.9352	19.7			Field test; retort leaked.
25	19	2 N.	97	8 1	150 lbs.		1,360.0	4.78+	.9169	23.7			Do.
26	19	2 N.	97	8 1	1 lb.	7.4		3.85	.9050	24.7			Field test.
27	11	1 N.	97	18 1	6 ounces.	6.0		8.4	.8946	26.5	1,926	18.3	Laboratory test.
28	11	1 N.	97	4 0	6 ounces.	10.0		14.0	.9090	24.0	2,075	1.0	Do.
29	11	1 N.	97	4 0	1 lb.	22.2		12.5	.9082	24.1		8.5	Field test.
30	11	1 N.	97	4	1.5 lbs.	25.9		9.1				10.5	Do.
31	11	1 N.	97	17 0	1 lb.	29.6		15.5	.8880	27.6			Do.
32	11	1 N.	97	3 0	6 ounces.	29.0		40.6	.8838	28.4	3,832	8.5	Laboratory test.
33	11	1 N.	97	3 0	1 lb.	48.1		25.5	.8920	26.9			Field test.
34	11	1 N.	97	5 6½	1 lb.	42.5		23.0	.8884	27.6			Do.
35	11	1 N.	97	4 2	1 lb.	27.7		14.7	.8864	27.9			Do.
36	11	1 N.	97	3 3¾	8 ounces.	29.6		31.0	.8831	28.5		15.8	Do.

37	11	1 N.	97	5 8½	1 lb.	44.4		23.25	.8877	27.7			Do.
38	14	1 S.	97	5 11	6 ounces.	18.0		25.2	.8955	26.4	4,294	6.3	Laboratory test.
39	36	1 N.	96	3 0	1 lb.	25.9		13.7	.8986	25.8		8.2	Field test.
40	36	1 N.	96	3 8	1 lb.	22.2		12.5	.8959	26.3		4.48	Do.
41	36	1 N.	96	1 4	1 lb.	25.9		13.7	.8603	32.7		4.91	Do.
42	29	1 N.	97		10 ounces	3.7		.31					Do.
43	2	3 S.	95	4 9	1 lb.	17.7		9.4	.8897	27.4		5.72	Do.
44	2	3 S.	95	13 6	1 lb.	11.8		6.2	.9025	25.1		3.25	Do.
45	32	4 S.	94	9 1	6 ounces.	4.5		6.1	.9205	22.1	639	2.8	Laboratory test.
46	16	4 S.	94	5 2	1 lb.	22.2		12.5	.9037	23.2			Field test.
47	27	4 S.	94	2 0	6 ounces.	5.0		7.0	.9030	25.4	479	1.7	Laboratory test.
48	27	4 S.	94	4 0	1 lb.	29.6		15.5	.9331	20.0		.4	Field test.
49	27	4 S.	94	3 0	6 ounces.	7.5		10.5	.8955	26.4	4,071	7.4	Laboratory test.
50	6	6 S.	94	10 0	6 ounces.	29.0		40.6	.8790	29.2	1,916	4.3	Do.
51	6	6 S.	94	4 3	6 ounces.	20.0		28.0	.9126	23.4	4,294	7.3	Do.
52	22	6 S.	95	8	6 ounces.	17.5		24.5	.8636	32.1	1,198	4.4	Do.
53	22	6 S.	95	8	6 ounces.	25.0		35.0	.8802	29.0	3,500	8.7	Do.
54	22	6 S.	95	8 0	1 lb.	39.5		20.7	.8585	33.1			Field test.
55	22	6 S.	95	13 0	6 ounces.	11.0		15.4	.9070	24.3	1,443	3.2	Laboratory test.
56	22	6 S.	95	15 0	6 ounces.	8.0		11.2	.9265	21.1	1,198	4.0	Do.
57	1	7 S.	98		6 ounces.	46.5		65.3	.9115	23.6	4,549	7.0	Do.

[a] Hand specimen collected by W. T. Lee.

[b] Hand specimen collected by D. T. Day.

Results of distillations of samples of oil shale in the field in 1915.

Sample No.	Location.				Thickness of shale sampled.	Gravity of oil at 60° F.		Yield of oil per short ton of shale (U. S. gallons).	Yield of ammonium sulphate per short ton of shale (pounds).
	Sec.	T.	R.	State.		Specific gravity.	Degrees Baumé.		
					Ft. in.				
58	17	11 S.	25 E.	Utah	3 11	0.8989	25.74	23	5.04
59	17	11 S.	25 E.	do	1 0	.9327	20.10	9	4.59
60	17	11 S.	25 E.	do	2 2	.9019	25.22	12	4.38
61	17	11 S.	25 E.	do	6 7	.9041	24.85	10	3.92
62	20	11 S.	25 E.	do	3 11	.8983	25.85	18	5.37
63	20	11 S.	25 E.	do	4 3	.8998	25.59	32	6.96
64	20	11 S.	25 E.	do	6 2	.8870	27.83	15	4.09
65	20	11 S.	25 E.	do	6 6	.9090	24.01	32	5.45
66	20	11 S.	25 E.	do	6 6	.9052	24.66	55	9.65
67	20	11 S.	25 E.	do	6	.8745	30.09	90	6.89
68	20	11 S.	25 E.	do	6 2	.9112	23.64	31	6.99
69	20	11 S.	25 E.	do	3 2	.9021	25.19	19	5.04
70	20	11 S.	25 E.	do	5 9	.9260	21.18	14	4.98
71	20	11 S.	25 E.	do	7 0	.9098	23.88	7	3.48
72	20	11 S.	25 E.	do	6 2	.8775	29.54	7	2.25
73	20	11 S.	25 E.	do	4 8½	.9263	21.13	6	2.61
74	20	11 S.	25 E.	do	5 9	.8887	27.53	32	7.05
75	22	11 S.	25 E.	do	2 4	.9036	24.93	35	5.14
76	22	11 S.	25 E.	do	4 6	.9034	24.97	31	5.20
77	26	10 S.	25 E.	do	6 9	.8727	30.42	37	7.81
78	24	11 S.	25 E.	do	6 3	.8833	28.49	48	9.76
79	27	10 S.	25 E.	do	4 1			1	2.11
80	15	10 S.	25 E.	do	4 7	.9094	23.94	33	5.87
81	15	10 S.	25 E.	do	1 11	.9073	24.30	24	6.72
82	15	10 S.	25 E.	do	6 0	.9163	22.78	20	6.49
83	15	10 S.	25 E.	do	4 0	.8975	25.98	8	5.32
84	15	10 S.	25 E.	do	7 8	.8966	26.14	21	3.77
85	15	10 S.	25 E.	do	1 8	.8879	27.67	22	5.39
86	15	10 S.	25 E.	do	3 2½	.8934	26.70	37	6.52
87	15	10 S.	25 E.	do	1 ½	.8866	27.90	54	5.51
88	15	10 S.	25 E.	do	2 1	.8914	27.05	25	4.05
89	15	10 S.	25 E.	do	4 0	.9059	24.54	17	5.48
90	15	10 S.	25 E.	do	4 8	.8976	25.97	45	9.22
91	15	10 S.	25 E.	do	5 1	.8953	26.37	29	5.35
92	9	13 N.	99 W.	Wyoming	5 0	.8709	30.79	30	3.94
93 [a]	19	13 N.	103 W.	do	4 0	.8760	29.81	11	4.88
94 [a]	25	13 N.	104 W.	do	2 0	.8937	26.65	15	5.91
95	26	13 N.	108 W.	do	5 0	.9496	17.43	13	7.49
96	26	13 N.	108 W.	do	5 4	.9277	20.91	4	12.69
97	26	13 N.	108 W.	do	4 10	.9062	24.49	6	4.71
98	27	13 N.	108 W.	do	5 0			3	7.18
99	27	13 N.	108 W.	do	3 3½			19	9.32
100	27	13 N.	108 W.	do	5 0			3	9.52
101	13	13 N.	108 W.	do	2 7	.8994	25.65	34	5.70
102	13	13 N.	108 W.	do	4 0	.9060	24.52	15	8.50
103	23	14 N.	108 W.	do	2 11	.8818	28.77	32	6.62
104	23	14 N.	108 W.	do	11	.8892	27.44	20	4.39
105	9	14 N.	108 W.	do	4 2	.8885	27.56	7	2.47
106	11	14 N.	108 W.	do	7 2	.9183	22.45	9	11.14
107	36	16 N.	108 W.	do	5 3	.9022	25.18	21	5.69
108	36	16 N.	108 W.	do	6 0	.8925	26.86	13	5.06
109	17	17 N.	106 W.	do	5 9	.8798	29.12	11	5.51
110	17	17 N.	106 W.	do	6 3	.9190	22.34	19	9.82
111	17	17 N.	106 W.	do	5 4	.9111	23.66	19	8.81
112	17	17 N.	106 W.	do	5 1	.9075	24.26	9	7.59
113	17	17 N.	106 W.	do	5 3	.9050	24.69	10	5.10
114	17	17 N.	106 W.	do	4 6	.9143	23.12	11	3.86
115	17	17 N.	106 W.	do	4 6	.8848	28.22	9	2.28
116	17	17 N.	106 W.	do	4 10			4	3.02
117	27	16 N.	106 W.	do	8 1	.9003	25.50	19	8.68
118	27	16 N.	106 W.	do	5 6	.9120	23.50	14	5.50
119	19	17 N.	106 W.	do	5 0	.8963	26.19	12	7.17
120	19	17 N.	106 W.	do	5 0	.8702	30.88	14	7.93
121	16	17 N.	106 W.	do	4	.9456	18.05	14	11.19
122	9	17 N.	106 W.	do	7 3	.9077	24.23	14	4.27
123	9	17 N.	106 W.	do	6 6	.9197	22.22	19	2.74
124	8	18 N.	107 W.	do	5 9	.9027	25.09	13	5.80
125	8	18 N.	107 W.	do	3 3½	.8800	29.09	6	3.73
126	8	18 N.	107 W.	do	1 8	.9182	22.47	29	11.71
127	24	18 N.	107 W.	do	6 3	.9148	23.03	18	7.27
128	24	18 N.	107 W.	do	2 4	.8862	27.97	7	5.65
129	5	21 N.	107 W.	do	1 7	.8705	30.82	8	.69
130	5	21 N.	107 W.	do	5 0	.8837	28.42	10	.86
131	5	21 N.	107 W.	do	2 0	.8889	27.49	50	1.99
132			(b)		2 4	.8449	35.70	50	4.50

[a] Collected by A. R. Schultz from fissile shale described as Wasatch in U. S. Geol. Survey Bull. 381, p. 222, 1910.

[b] Collected by David White from a point near Elko, Nev.

OIL.

Most oils obtained from the distillation of shale are reddish brown, and at ordinary temperatures range from semisolid vaseline-like products to a thin liquid.

Samples 7, 8, 10, 11, 12, 18, 19, 21, 23, 24, and 25 were distilled in the large field retort, and the resulting oils have a specific gravity ranging from 0.9109 (23.7° Baumé) to 0.9371 (19.4° Baumé). The oils obtained from samples distilled in the small apparatus range in specific gravity from 0.8449 (35.7° Baumé) to 0.9496 (17.4° Baumé), though by far the larger number of samples show a specific gravity of less than 0.90 (25.0° Baumé). The difference in the oils obtained by using the large and small apparatus is probably due to conditions of heating rather than to differences in original material, but the oil from all samples distilled in a particular apparatus may be assumed to have been obtained under conditions approximately similar. About one-fourth of the distillations were made in the Washington laboratory of the Bureau of Mines, with an apparatus similar to the small outfit used in the field. In order to compare the tests made in the laboratory with those made in the field with the small apparatus, shale from two samples tested in the field was tested in the laboratory, and the results were found to check very closely.

It was suggested at the beginning of the oil-shale investigations that distillation of shale with the injection of steam into the heated retort might result in a product of increased value, but before 1914 no sample had been treated in such a way that a comparison of the value of dry and steam distillation could be made. The writer therefore during the first field season selected a sample of shale and, after careful mixing, divided the sample into two equal parts (142 pounds each). One part was distilled dry and the other part distilled in the same apparatus on the following day with the addition of steam to the heated mass. From the dry-distilled sample (No. 19) oil was obtained at the rate of 6.27 gallons to the ton of shale; the steam-distilled sample (No. 18) yielded 22.88 gallons of oil to the ton. It is not likely that the larger yield of oil obtained from the second sample could be entirely due to the effect of the steam, and it is probable that to other factors, such as leakage, may in part be due the difference in quantity of oil obtained under the two methods of distillation. That the oil produced by steam distillation is not radically different from that produced by dry distillation is shown by the similar proportion of products which the oils yield on fractionation. (See table, p. 156.) It is unfortunate that in this test, the only one made on a large sample, there was no equipment available to ascertain the effect of steam distillation on the yield of ammonium sulphate. Later, six samples of oil shale were distilled with steam at the Washington laboratory of the Bureau of Mines.

For these samples the quantity of oil derived by steam distillation exceeded that by dry distillation only slightly or in some samples not at all. At the same time the oil produced by steam distillation has a uniformly heavier gravity. The detailed results of these tests are given on page 160.

Oils from nine samples treated in the field and in the laboratory were redistilled with the following results:

Results of fractionation of shale oil.

Sample No.	4	6	10	18	19	27	32	51	57
Begins to boil at °C.	80	52	50	70	72	65	80	70	54
Distillation (cubic centimeters):									
To 100° C.	6	10	2	2.5	2	4	2.5	7	4
100 to 125° C.	2	.5	3.5	1	1	1.5	3.5	1	2
125 to 150° C.	2	1.5	6.5	2.5	8	1.5	4.5	1	3
Total gasoline	10	12	12	6	11	7	10.5	9	9
150 to 175° C.	2	2	8	6	6.5	3	6	2	5
175 to 200° C.	2	4	6	5	5	3	5	4	4.5
200 to 225° C.	5	4	7.5	5	5	4	6	4	5
225 to 250° C.	7.5	6	7	5	5	5	8	6	5
250 to 275° C.	6	6	7.5	7	7	7	8.5	6.5	7
275 to 300° C.	6	10	13	7	7	17	9	13	12
Total kerosene	28.5	32	49	35	35.5	39	42.5	35.5	38.5
Total distillate	38.5	44	61	41	46.5	46	53	44.5	47.5
Total residuum	61.5	56	39	59	53.5	54	47	51.5	52.5
Amount of oil used	100	100	100	100	100	100	100	96	100
Specific gravity at 60° F.:									
Crude	0.8937	0.8850	0.9138	0.9290	0.9327	.08946	0.8838	0.9126	0.9126
Gasoline	.7947	.7769	.8090	.7974	.8202	.7849	.7568	.7838	.7605
Kerosene	.8602	.8466	.8260	.8742	.8876	.8722	.8524	.8682	.8538
Residuum	.9695	.9643	.9884	.9894	1.0160	.9684	.9368	.9695	.9628
Asphalt, per cent by weight	1.35	.82	2.82	4.10	3.62	2.49	.47	1.40	1.03
Paraffin, do	7.70	6.93	2.22	3.72	1.63	4.56	4.70	9.21	4.00
Sulphur, do	.54	1.06	.....	.....	.....	.73	1.42	.41	.69
Nitrogen, do	1.848	.887	2.198	1.549	1.643	1.267	1.849	1.820	2.135
Unsaturated hydrocarbons:									
Crude, per cent	.....	.....	82	86	81.6	.....	72	.....	.....
Kerosene, do	55	55	64	71	71	61	57	62	58

A study of the table reveals a fairly uniform quantity of products from the different samples, the gasoline ranging from 6 to 12 per cent, the kerosene from 28.5 to 49 per cent, the paraffin from 1.63 to 7.70 per cent, and the sulphur from 0.41 to 1.42 per cent. The samples for fractionation were chosen to illustrate both range in physical character of the shale and wide geographic distribution. Sample 4 was from massive shale obtained near Soldier Summit, Utah (for location see Pl. X); sample 6, from brown shale near Elko, Nev.; sample 10, from massive shale in sec. 9, T. 1 N., R. 103 W., Colo. (see Pl. XVIII); samples 18 and 19, from massive shale in sec. 16, T. 2 N., R. 98 W., Colo. (No. 18, steam distilled; No. 19, same sample, dry distilled); sample 27, from papery shale in sec. 11, T. 1 N., R. 97 W., Colo.; sample 32, from massive shale in sec. 11, T. 1 N., R. 97 W., Colo.; sample 51, from massive shale in sec. 6, T. 6 S., R.

94 W., Colo.; sample 57, from massive black shale in sec. 1, T. 7 S., R. 98 W., Colo.

The samples, except No. 27, were obtained within a few inches of the outcrop and probably were slightly weathered, although physical evidence of weathering in the type of shale sampled extends only a very short distance back from the outcrop. As the papery shale weathers to considerable distance back from the outcrop a drift 18 feet long was driven for the purpose of obtaining a sample (No. 27), but the zone of weathering had not been passed at the point of sampling.

In order to determine the behavior of shale oil when subjected to the Rittman process [1] of refinement, two samples were tested at the Pittsburgh laboratory of the Bureau of Mines. The only samples of shale oil available for these tests were two obtained by Woodruff [2] in 1913 from field distillations of shale described below. The samples had remained sealed since the date of original distillation and were therefore probably not greatly altered. Each sample was fractionated in the ordinary way with the following results:

Fractionation of shale oil by ordinary method.

Distillation—	Sample A: Specific gravity, 0.882; boiling point, 32° C.		Sample B: Specific gravity, 0.925; boiling point, 25° C.	
	Percentage by weight.	Specific gravity.	Percentage by weight.	Specific gravity.
To 75° C	3.4	0.691	2.5	0.700
75° to 100° C	2.4	.738	1.6	.....
100° to 125° C	4.8	.754	3.6	.772
125° to 150° C	5.6	.775	5.5	.792
150° to 175° C	6.4	.795	5.8	.814
175° to 200° C	6.6	.821	6.7	.842
200° to 225° C	6.8	.844	6.1	.862
225° to 250° C	7.2	.866	6.4	.884
250° to 275° C	9.4	.892	7.2	.913
275° to 300° C	8.7	.901	9.0	.929
Residuum	38.5	Solid.	43.0	Solid.

The residuum over 175° C. of each sample (A and B) was then divided into two parts (A and A′, B and B′) and run in a Rittman furnace with 150 pounds pressure, different temperature being used for each part, as indicated below.

A. Subsurface sample from north side of White River, 5 miles east of White River stage station, T. 9 S., R. 25 E., Utah. Bed, 3 feet 6 inches thick. Yield, 33.3 gallons of oil to the short ton of shale.

B. Sample obtained 4 miles north of Ninemile Creek, approximately in sec. 12, T. 11 S., R. 16 E., Utah. Bed, 6 inches thick. Yield, 39 gallons of oil to the short ton of shale.

[1] Rittman, W. F., Dutton, C. B., and Dean, E. W., Manufacture of gasoline and benzene-toluene from petroleum and other hydrocarbons: Bur. Mines Bull. 114, 1916.

[2] Woodruff, E. G., and Day, D. T., op. cit. pp. 4, 19, 20.

Rittman furnace tests on residuum obtained from distillations of shale oil at temperature over 175° C. Pressure 150 pounds (gage reading).

	Sample A.	Sample A′.	Sample B.	Sample B′.
Temperature used (°C.)	525	550	525	600
Specific gravity of residuum	0.920	0.920	0.957	0.957
Specific gravity of recovered oil	.901	.902	.929	.959
Percentage recovery	79	79	82	70

The oil recovered from the treatment in the Rittman furnace was then distilled with the following results:

Distillation of oil recovered from Rittman tests of shale oil.

	Sample A.	Sample A′.	Sample B.	Sample B′.
Specific gravity of recovered oil	0.901	0.902	0.929	0.959
Distillation (per cent by weight)—				
To 75°	.....	4.2	.....	3.8
To 100°	2.2	[a] 6.2	2.8	[a] 1.8
100° to 125°	1.1	8.5	1.1	2.5
125° to 150°	1.4	10.7	1.6	2.7
150° to 175°	2.7	13.8	3.0	4.2
175° to 200°	7.0	20.0	6.3	6.9

[a] Distillation, 75° to 100° C.

An examination of the above tables shows that by ordinary methods of fractionation Samples A and B will yield 22.6 and 19.0 per cent, respectively, of distillate up to 175° C. Treatment of the residuum above 175° C. in the Rittman furnace with 150 pounds pressure and temperatures of 525° to 600° C. produces an oil which will yield additional fractions below 175° C. according to the temperature used in the furnace. Tests of two samples of shale oil do not furnish adequate data for generalizations but merely indicate that under proper treatment shale oil may be made to yield a much larger percentage of gasoline than that shown in the tables on pages 156 and 157.

AMMONIUM SULPHATE.

Inasmuch as one of the valuable products derived from the distillation of shale in Scotland is ammonium sulphate, it is interesting to compare the amount of nitrogen in the shale with the amount that is accounted for in the products of distillation. The following table is based on the assumption that all the nitrogen in the shale can be converted to ammonium sulphate:

Relation between total amount of nitrogen in shale and amount accounted for in products of distillation.

Sample No.	Nitrogen in shale.	Theoretical equivalent of nitrogen in ammonium sulphate (per ton of shale).	Yield of oil per ton of shale.	Nitrogen in oil.	Equivalent ammonium sulphate (per ton of shale).	Ammonium sulphate extracted from gas (per ton of shale).	Total nitrogen accounted for in ammonium sulphate (per ton of shale).	Total nitrogen unaccounted for in ammonium sulphate (per ton of shale).
	Per cent.	*Pounds.*	*Gallons.*	*Per cent.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
4	0.39	36.6	16.8	1.848	10.9	3.5	14.4	22.2
6	.39	36.6	86.8	.887	26.7	6.0	32.7	3.9
27	.46	43.2	8.4	1.267	3.7	18.3	22.0	21.2
32	.54	50.8	40.6	1.849	26.1	8.5	34.6	16.2
51	.46	43.2	28.0	1.820	18.2	7.3	25.5	17.7
57	1.22	115.0	65.3	2.135	50.0	7.0	57.0	58.0
63	.53	49.9	32.0	(a)	(a)	7.0	(a)	b 42.9
64	.35	33.0	15.0	(a)	(a)	4.1	(a)	b 28.9
65	.73	68.8	32.0	(a)	(a)	5.4	(a)	b 63.4
66	.80	75.4	55.0	(a)	(a)	(a)	(a)	(a)
67	1.30	122.5	90.0	(a)	(a)	6.9	(a)	b 115.6
68	.70	66.0	31.0	(a)	(a)	7.0	(a)	b 59.0
69	.32	30.1	19.0	(a)	(a)	5.0	(a)	b 25.1
74	.43	40.5	32.0	(a)	(a)	7.1	(a)	b 33.4
77	.68	64.1	37.0	(a)	(a)	7.8	(a)	b 56.3
92	.60	56.7	30.0	(a)	(a)	3.9	(a)	b 52.8
101	.68	64.1	34.0	(a)	(a)	5.7	(a)	b 58.4
129	.10	9.4	8.0	(a)	(a)	.7	(a)	b 8.7
131	.50	47.1	50.0	(a)	(a)	2.0	(a)	b 45.1
132	.85	80.1	50.0	(a)	(a)	4.5	(a)	b 75.6

a Not determined.
b Nitrogen unaccounted for is much greater in these samples because the amount in oil was not determined.

It will be noticed that in no test has the entire amount of nitrogen present in the shale been accounted for in the products of distillation, and except for one sample (No. 6) there is a larger amount of nitrogen unaccounted for than the amount which was extracted from the fixed gas in the form of ammonium sulphate. In the samples tested the amount of ammonium sulphate extracted from the permanent gas averages 11.1 per cent of the theoretical total amount of ammonium sulphate available from the shale, and an average of 41 per cent of the theoretical total available ammonium sulphate is accounted for by the nitrogen in the shale oil itself. Therefore the theoretically available ammonium sulphate unaccounted for averages more than twice as much as is extracted from the gas produced in the distillation of the shale. In the shale works of Scotland distillation is carried on with the injection of steam, which results, according to Steuart,[1] in practically doubling the amount of ammonium sulphate that is extracted from the permanent gas by the dry method. The table given above indicates that there is ample nitrogen in the shale to allow the extraction of double the amount of ammonium sulphate obtained in the dry distillation, provided the right process is used.

[1] Steuart, D. R., The oil shale of the Lothians, 2d ed., p. 144, Scotland Geol. Survey Mem., 1912.

During May, 1916, six samples of oil shale were tested at the Bureau of Mines, with an apparatus similar to that used in the field, but so arranged that superheated steam was injected into the retort during the entire process of distillation. The samples were selected to represent a wide geographical distribution, as well as differences in richness and physical character, and the results of the tests are extremely interesting. Each of the samples had been tested previously in the field apparatus without steam, and the results therefore furnished factors that may be used to convert the results of field tests into what are very probably close approximations to results to be expected from commercial practice.

Comparison of steam and dry distillation.

Sample No.	Oil.				Ammonium sulphate.		
	With steam.		Without steam.		Theoretical yield, equivalent of nitrogen in shale (pounds per ton).	Yield as determined.	
	Yield (gallons per ton).	Specific gravity.	Yield (gallons per ton).	Specific gravity.		With steam (pounds per ton).	Without steam (pounds per ton).
4.....	23.0	0.9346 (19.7° B.)	16.8	0.8937 (26.6° B.)	36.6	13.4	3.5
27.....	10.0	.9135 (23.2° B.)	8.4	.8946 (26.5° B.)	43.2	29.9	18.3
32.....	44.0	.9630 (15.3° B.)	40.6	.8838 (28.4° B.)	50.8	34.0	8.5
51.....	39.0	.9234 (21.6° B.)	28.0	.9126 (23.4° B.)	43.2	15.8	7.3
66.....	55.0	.9286 (20.7° B.)	55.0	.9052 (24.6° B.)	75.4	23.1	9.6
132.....	50.0	.9109 (23.7° B.)	50.0	.8449 (35.7° B.)	80.1	8.4	4.5

The average amount of ammonium sulphate produced from the shale by steam distillation was about two and one-half times the amount obtained from the same samples by dry distillation, thus providing a factor for the conversion of the figure for ammonium sulphate by dry distillation to ammonium sulphate which may be obtained with steam distillation (the method practiced in the oil-shale industry of Scotland and France).

In the six samples tested an average of 37.8 per cent of the nitrogen in the shale was accounted for in the ammonium sulphate obtained by steam distillation, compared with an average of 15.7 per cent recovered by dry distillation. During the two seasons the yield of ammonium sulphate was determined for 57 of the samples that yielded more than 15 gallons of oil to the ton of shale. In these samples an average of 6.7 pounds of ammonium sulphate to the ton was obtained. This multiplied by 2.5, the factor mentioned above, gives an average of 16.7 pounds of ammonium sulphate to the ton, which seems to be a fair estimate of the quantity that may be produced in commercial practice from shale of the area examined in 1914 and 1915.

CHEMICAL ANALYSES OF OIL SHALE.

Shale samples 4, 6, 27, 32, 51, and 57 were analyzed by methods used in making ultimate analyses of coal, with the following results:

Analyses of samples of shale from the Green River formation in Colorado, Utah, and Nevada.

[Made at the Washington laboratory of the Bureau of Mines; J. D. Davis, chemist in charge.]

Sample No.	Location.			Form of analysis.[a]	Proximate.				Ultimate.					Heating value (British thermal units).
	Sec.	T.	R.		Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	
4	(b)	.....	.....	A	1.05	33.55	(c)	65.43	0.27	1.80	13.37	0.39	18.74	2,266
				C	.....	33.91	(c)	66.12	.28	1.70	13.51	.39	18.00	2,290
6	(d)	.....	.....	A	1.05	45.04	(c)	45.73	1.07	5.19	36.76	.39	10.86	7,714
				C	.....	45.52	(c)	46.21	1.08	5.13	37.15	.39	10.04	7,796
27	11	1 N.	97 W.	A	3.18	19.55	(c)	79.00	1.08	1.75	8.34	.46	9.37	1,157
				C	.....	20.19	(c)	81.59	1.12	1.44	8.61	.48	6.76	1,195
32	11	1 N.	97 W.	A	.45	37.90	(c)	62.65	.55	2.76	22.48	.54	11.02	4,012
				C	.....	38.07	(c)	62.93	.55	2.72	22.58	.55	10.67	4,030
51	6	6 S.	94 W.	A	.43	39.85	(c)	59.95	.30	2,24	18.87	.46	18.18	3,055
				C	.....	40.02	(c)	60.21	.30	2.20	18.95	.46	17.88	3,068
57	1	7 S.	98 W.	A	.85	51.60	(c)	46.23	.95	4.32	36.40	1.22	10.88	6,976
				C	.....	52.04	(c)	46.63	.96	4.26	36.71	1.23	10.21	7,036

[a] Analysis A represents the composition of the sample as it comes from the ground. Analysis C represents the theoretical condition of the shale after all the moisture has been eliminated.

[b] Soldier Summit, Utah.

[c] The conditions of heating in the volatile matter determination are different from those in the ash determination, and owing to different reactions the quantity of inorganic residue is not the same in both. As a result, the value of the fixed carbon is for some examples negative.

[d] Elko, Nev.

In addition to the ultimate analyses shown above, the percentages of nitrogen and sulphur in 14 samples of shale tested for oil in 1915 were determined, with the following results:

Partial analyses of samples of shale from Utah and Wyoming.

[Made at the Washington laboratory of the Bureau of Mines; J. D. Davis, chemist in charge.]

Sample No.	Location.				Nitrogen.	Sulphur.
	Sec.	T.	R.	State.		
					Per cent.	*Per cent.*
63	20	11 S.	25 E.	Utah	0.53	0.58
64	20	11 S.	25 E.	do	.35	.31
65	20	11 S.	25 E.	do	.73	.70
66	20	11 S.	25 E.	do	.80	.87
67	20	11 S.	25 E.	do	1.30	1.59
68	20	11 S.	25 E.	do	.70	.58
69	20	11 S.	25 E.	do	.32	.81
74	20	11 S.	25 E.	do	.43	.42
77	26	10 S.	25 E.	do	.68	.56
92	9	13 N.	99 W.	Wyoming	.60	.71
101	13	13 N.	108 W.	do	.68	1.66
129	5	21 N.	107 W.	do	.10	.77
131	5	21 N.	107 W.	do	.50	2.78
132	(a)	.....	.....	.....	.85	5.15

[a] Elko, Nev.

GEOLOGY.

THE SHALE.

The Green River formation, of early Tertiary (Eocene) age, consists predominantly of shale. It exhibits on the weathered outcrop a more or less white color, but closer examination reveals an alternation of gray, bluish gray, and white bands. (See Pls. XI and XIII.) The shale that yields the most oil when subjected to distillation is that which weathers into massive benches of grayish-blue color but which is dark brown to black on a freshly broken surface. After this tough rich shale, which appears to be without bedding planes or laminations, is heated and the oil driven off it crumbles easily and exhibits true shale structure. Where thin benches of rich shale are interbedded with lean or barren shale, the former, being resistant, weathers to projecting ledges. (See Pl. XIV, *A*.) Some of the very rich beds show a vitreous luster similar to that of coal. The massive shale (Pl. XVI, *A*) is exceedingly tough, resists erosion to a remarkable degree, and as it weathers to a bluish-white surface and will burn when ignited the ranchers of some parts of the region refer to it as "white rock that will burn." When freshly broken, the shale gives off an odor of petroleum. All gradations exist between this hard, tough, massive rock and the papery shale (Pl. XVI, *B*), which weathers to curly forms. The papery shale is in a few places black, but usually light brown, and the thin plates of weathered shale are remarkably flexible, a characteristic which distinguishes it from ordinary carbonaceous shale. Weathering affects the papery shale to a distance of more than 20 feet back from the outcrop, but, except along joint planes, the hard, massive shale shows little evidence of weathering for more than a quarter of an inch from the exposed surface. Oil has been distilled from the papery shale as well as from the hard, massive variety, although in smaller quantity.

The hard, rich shale that crops out as projecting ledges and weathers to a gray or grayish-blue color is dark brown to black on the unweathered surface, and in all probability weathering does not affect the oil-yielding capacity of the shale to any considerable depths. Most of the samples for distillation were taken after chipping away the part of the bed that had been changed from dark to light color, and for most of the samples this required the removal of only an inch or two of weathered shale. In order to determine the difference between the shale just back of this obviously weathered zone and that a foot or so deeper samples 65 and 66 were taken from a single bed near Watson, Utah. Plate XIV, *B*, shows the relative position of the materials for the two samples, as well as the manner in which the fresh shale breaks when mined. Sample 66 was obtained after blasting away an average of about 18 inches of outcrop shale; sample

65 was taken within an inch or two of the weather-exposed face. The yield of oil for sample 65 was at the rate of 32 gallons to the short ton, but sample 66 gave nearly twice as much, or 55 gallons of oil to the ton.

Inasmuch as the samples of shale for the tests listed on pages 152–154 were obtained near the outcrop, like sample 65, it is safe to assume that the results given in this paper do not represent the maximum yield that may be obtained from the same shale when it is mined.

Although oil may be obtained from the shale by destructive distillation, it does not appear that more than a small percentage exists in the shale as oil; at least oil has not been found in commercial quantity in two wells that have been drilled into the shale in northwestern Colorado. The "gas well" in sec. 22, T. 1 N., R. 97 W., is about 400 feet deep, and develops a strong flow of artesian water, together with considerable gas, but no oil. This well does not reach the richest shale beds. Another well, drilled to a depth of 1,345 feet in sec. 30, T. 2 S., R. 94 W., apparently passes through the Green River formation and penetrates the underlying Wasatch formation, but develops only a show of oil, and that apparently near the contact between the two formations. A spring in sec. 14, T. 1 N., R. 97 W., east of Piceance Creek, issues from between two rich beds of shale. The water is of excellent quality and does not show any evidence of oil or gas.

The following description of the microscopic structure of the shale was furnished by Charles A. Davis, who at the time of his death was engaged in making a careful study of the rocks with special attention to their fossil content:

The shale as seen under the microscope varies as greatly in appearance and structure as it does when examined with the unaided eye, according to the locality and bed from which the material examined originally came. The darker specimens yield sections showing characteristic opacity, density, and compactness of structure and fineness of grain. The lighter-colored samples show less opacity and appear more granular, even when casually examined. Specimens from the same sample also present quite different appearances, according to the direction in which the section is cut.

Under low powers of the compound microscope sections cut transverse to the bedding planes show a more or less distinct lamination or banded structure, the dark-brown to light-yellow bands alternating irregularly with colorless or light-grayish ones. Usually the dark bands of the section are longer and more continuous than the light bands.

Under higher magnifications these bands resolve themselves into a series of more or less discontinuous thin laminæ, of which the brown and yellow or dark ones are certainly longer and more continuous than the gray or colorless ones. Careful inspection shows that the dark laminæ are usually not easily resolvable into granules, while the light ones are obviously made up chiefly of particles of crystals of mineral matter; much of the mineral matter is very finely divided, although some sand is present. Moreover, most of the laminæ containing mineral matter are lens-shaped, and in the samples in which they were carefully examined many of them were found to

be from two to eight or ten times as long as they are thick, and the darker laminæ in the same sections are characteristically many times longer than they are thick.

In addition to these general characteristics shown in the cross sections the samples exhibit the following features:

1. Well-marked openings, in places of polygonal or even square outline, but more commonly of irregular lens shape or the shape of a flattened sphere. The larger of such openings occur usually in the lenses of mineral matter that is in the form of coarse particles. Some of these openings still contain bits of crystalline minerals, and others contain fine silty residues. It is thus evident that the openings themselves may have been formed by the breaking up of the original filling, which corresponds to that of the shorter, lens-shaped laminæ, during the cutting of the section.

2. Irregularly distributed black opaque bodies, which glisten by reflected light. These fill lenslike openings that seem identical with those just described, as well as other openings, including the irregularly polygonal matrices of minerals. The material forming the opaque bodies only partly fills some of the openings in which it occurs. Such partly filled spaces show by their irregular filling and by the relation of the opaque matter to included minerals that they have been filled by local intrusion from the surrounding walls, as the material has not yet been observed running from one cavity to another, and unfilled cavities are numerous near and between those that are filled.

3. Very dark brown or black lines, which seem to represent the edges of vegetable structures such as fibers, filaments, or films that are of different composition or are more fully carbonized than the general mass of material with which they were laid down. These dark lines are in places interlaminated with light-colored organic matter and clearly can not be considered as intrusions into the laminated material after it was laid down, as the whole series of laminæ is in places very finely wrinkled and each individual layer is of extreme thinness, many being less than a micron thick. As these very thin light-colored laminæ are entirely conformable with the thinnest dark ones, they must have been laid down with them. The thicker dark laminæ, being more opaque than the light ones, can not be so readily resolved for measurement, but where they have been carefully studied they show minute secondary lamination as well as the inclusion of thin lines of inorganic sediment, a structure which clearly proves their sedimentary origin and entirely undisturbed condition.

The wide range of variation in the characteristics of the structure, bedding, and grain of the different samples of shale examined makes it impossible to discuss all the variations which have been found, but the points brought out are the most striking ones noted in examining the cross sections.

A study of sections made parallel with the bedding planes of the oil-yielding shale shows also a large number of variations, even in the same fragment. The dark samples in general give the most interesting sections, the lighter-colored ones showing chiefly finely divided amorphous particles of mineral matter, mixed with crystalline particles, which are possibly of secondary origin, and with scattered fragments which from their color and structure are easily recognizable as of organic origin—that is, derived from the remains of plants or animals.

The examination of a large number of horizontal sections shows that the laminæ are not generally flat or perfectly horizontal, but rather occur in undulating bands, apparently formed while the material was still in the process of deposition. Some horizontal sections of darker samples show only slightly granular or nearly homogeneous texture, with no inclusions. Other sections show a large number of minute plants and plant remains that are surprisingly well preserved. In general, these plant remains are embedded in the same sort of material of which the seemingly structureless sections are composed. Some of this structureless material can be resolved by careful manipulation to show a granular structure, and under such conditions the shadowy outlines of plant remains can be seen in some sections.

The inference is clear that the structureless material probably originated in a collection of plant débris which has by decomposition and the activities of bacteria and other microscopic organisms passed into a jelly-like phase such as is to be found in certain kinds of modern peat deposits. The plant remains that have been found in the shale from every locality which has furnished samples are those of microscopic algæ mixed in smaller percentage with pollen and similar parts of higher plants. Animal remains are rare in the material studied, and those noted were chiefly the remains of insects in a very fragmental state.

It seems apparent, therefore, that the study of the microscopic structure of this shale as seen in vertical and horizontal sections leads to the conclusion that the material was laid down originally in water and that it passed through a series of stages of decomposition before consolidation and lithification had taken place. The remarkably well preserved state of the delicate plant structures which have been examined indicates very slight disturbances of the original material and an almost entire lack of changes produced by the action of the usual metamorphosing agencies since lithification.

STRATIGRAPHY.

The oil-yielding shale is confined almost entirely to the middle part of the Green River formation, and during the present examination little attention was paid to rocks of other formations. In northwestern Colorado the Green River formation is the youngest present, but north of White River and only a few miles west of the Colorado-Utah line the Bridger formation rests unconformably on the Green River as well as older formations, and along the northern edge of the Uinta Basin in Utah the Bridger obscures the entire outcrop of the oil shale. The Bridger formation also occupies the central part of the Green River basin in southwestern Wyoming and west of Burnt Fork and south of Carter overlaps the Wasatch formation, covering the outcrop of the Green River.

The Green River formation is underlain by the Wasatch and this in turn by the Mesaverde, which in Colorado and Utah is coal bearing. The Wasatch in Wyoming contains valuable beds of coal, which may be needed for fuel when the shale-oil industry is developed.

The Green River formation has a maximum thickness near the mouth of Piceance Creek of about 2,600 feet and may be separated there on the basis of the presence or absence of oil-yielding shale into three fairly distinct parts. The upper and lower parts of the formation are practically barren, but the middle part of the formation contains, at every locality examined, beds of shale that will yield considerable oil. A single test was made of shale from the upper division of the formation, which yielded 0.31 gallon of oil to the ton of shale (sample 42, p. 153). The section measured near the mouth of Piceance Creek (H, pp. 177–178) shows the oil-yielding part of the formation to be 1,550 feet thick, whereas the lower barren part is only 342 feet thick and the upper barren part 716 feet thick. According to measurements made near Morris station (O, p. 182) on the Book Cliffs, the upper 595 feet of the section there exposed is

oil yielding, but the underlying part, 1,487 feet thick, includes no beds that will yield any appreciable quantity of oil. The great thickness of lower barren beds near Morris corresponds very closely with the thickness of the lower part of the formation as described by Woodruff [1] in a section measured along the Mount Logan trail in sec. 26, T. 7 S., R. 97 W., only a few miles to the west and on the same general cliff. In general the lower member of the Green River formation is extremely variable both in thickness and character. Along Evacuation Creek, near Dragon, Utah (sec. Q, pp. 183–184), this member includes about 600 feet of coarse sandstone, oolite, and shale with no persistent bed and some very remarkable lenticular beds. Only a few miles away, in Hells Hole Canyon, northwest of Watson (sec. T, pp. 185–186), the lower part of the Green River formation includes largely shale with comparatively thin sandstone beds and only a little oolite.

In contrast to this extreme irregularity in the lower part of the formation the thin beds of the oil-yielding portion are remarkably persistent. Sections Q, S, and T, representing the strata exposed at three places in eastern Utah, separated from one another by 5 and 7 miles (see Pl. XVIII), show three thin beds of sandstone which are remarkably regular in thickness, and at the same time the interval between them varies only slightly from place to place.

The line between the Wasatch and Green River formations is very difficult to follow because of lack of exposures and very hard to identify accurately from place to place. There seems to be a general gradation from the upper part of the Wasatch formation into the lower part of the Green River, and it is possible that the correlations shown on Plate XVII are not absolutely correct.

The Green River formation consists principally of shale but contains, especially in its lower part, beds of sandstone, many of which are ripple marked. Most sections show one or more beds of oolite and some conglomerate or conglomeratic sandstone. Near the old Black Dragon mine, Utah, however, the lower part of the formation, according to measurements made by Woodruff,[2] contains oolite and sandstone equal to more than half of the exposed thickness of beds (529 feet). There is at the base of the upper part of the formation on Yellow and Piceance creeks a bed of massive brown sandstone which may be equivalent to the Tower sandstone of Powell [3] in southwestern Wyoming. As is shown by the sections given below, there are in nearly every section many beds of shale that will yield at least 15 gallons of crude oil to the ton, but the correlation of beds from one measured section to another, although the sections may be

[1] Woodruff, E. G., and Day, D. T., op. cit., p. 14.
[2] Idem, pp. 16, 17.
[3] Powell, J. W., Geology of the eastern portion of the Uinta Mountains, pp. 40–45, U. S. Geol. and Geog. Survey Terr., 2d div., 1876.

only a few miles apart, is very uncertain. A careful study of the strata exposed in a continuous cliff face a mile or more in extent shows that although the formation appears to be remarkably regular in thickness, individual beds vary greatly from place to place and that a single massive bed 5 feet thick at one place may change to comparatively thin-bedded shale within less than half a mile. Study of any single bed at several places along its outcrop to determine its variability in thickness, bedding, mode of weathering, and value as a source of oil was made impossible by lack of exposures except near the mouth of Piceance Creek in Colorado and along the west side of Green River in southwestern Wyoming. In the Colorado locality a zone of oil-producing shale was examined, carefully measured, and sampled at three localities within a distance of approximately 1,100 feet along its outcrop with the following results:

Sections of oil-shale zone along the west side of Piceance Creek, Colo., in sec. 11, T. 1 N., R. 97 W.

Location 34.[1]

	Ft.	in.
Shale, hard, black	1	2
Shale, light brown		3
Shale, dark brown		2
Shale, light brown		1
Shale, hard, black		7
Shale, light brown		½
Shale, hard, black, in beds 2 inches thick		6
Shale, brown		2½
Shale, hard, dark		2
Shale, brown, lean [2]		2
Shale, hard, dark		3
Shale, brown		½
Shale, hard, dark		1
Shale, lean		4½
Shale		1
Shale, hard, black	1	2
	5	4

Location 35, 100 feet N. 7° E. of location 34.

	Ft.	in.
Shale, dark brown		2
Shale, hard, dark brown		2
Shale, hard, black		1½
Shale, sandy, lean	1	4
Shale, brown, rich		5
Shale, hard, brown		3
Shale, brown, rich		11
Shale, hard, brown		2
Shale, rich		3
Shale, hard, brown		1½
Shale, brown, lean		3
	4	2

Location 36, about 1,000 feet N. 10° E. of location 35.

	Ft.	in.
Shale, hard, dark		1
Shale, brown, thin bedded		1
Shale, hard, dark		4½
Shale, lean		½
Shale, hard, black		5½
Shale, brown		¼
Shale, hard, black		4
Shale, brown		1½
Shale, hard, black		8½
Shale, brown		½
Shale, hard, black		4½
Shale		1
Shale, hard, black		3
Shale, brown, lean		4
	3	3¾

[1] Location numbers correspond to those used on the maps. Stratigraphic sections are arranged so that the youngest beds are described first and successively older beds follow.

[2] In this paper the term "lean" is applied to shale that will yield less than 15 gallons of oil to the short ton and "rich" to shale that will yield more than 15 gallons.

Samples from these localities when subjected to distillation gave the following results:

Results of distillation of samples from three localities on a single bed of shale on the west side of Piceance Creek, sec. 11, T. 1 N., R. 97 W.

Location No.	Total thickness sampled.	Yield of oil per ton of shale.	Gravity of oil.
	Ft. in.	*Gallons.*	
34	5 4	23.0	0.888 (27.6° B.)
35	4 2	14.7	.887 (27.9° B.)
36	3 3½	31.0	.883 (28.5° B.)

This zone contains shale which on weathering resembles somewhat closely a massive bed but which may be subdivided upon close examination into a number of very thin units differing from one another only in minor particulars. The gravity of the oil derived from these samples is fairly uniform, but the quantity differs widely. It is possible that part of this difference in yield may be due to changes produced by weathering, although if such were the case it would seem that the gravity of the oil in sample 35 would show a corresponding increase. However, the data at hand are not sufficient to make generalizations.

Along both sides of Green River, Wyo., in Tps. 13 and 14 N., R. 108 W., a single bed or zone of rich oil-yielding shale is exposed in almost continuous outcrop for several miles. The bed is made up of alternating thin benches of rich and lean shale which weather into a most characteristic form, so that the bed can be easily identified from place to place. The richer benches weather to grayish-blue ledges which project beyond the softer lean shale, as shown in Plates XIII, *B*, and XIV, *A*. In places slabs 3 or 4 feet square and only an inch thick have weathered out and lie scattered over the surface. The four sections given below illustrate the variability of the different parts of the bed. The results of the field distillations of samples taken at three of the places are given in a separate table following.

Sections of shale bed along Green River, Wyo.

Location 99, sec. 27, T. 13 N., R. 108 W.

	Ft.	in.
Shale, hard, black, rich		½
Shale, soft, brown, lean		5
Shale, hard, black, rich		1
Shale, soft, brown, lean		8
Shale, hard, black, rich		2
Shale, soft, brown, lean	1	8
Shale, hard, black, rich		3
	3	3½

Sections of shale bed along Green River, Wyo.—Continued.

Location 101, sec. 13, T. 13 N., R. 108 W.

	Ft.	in.
Shale, hard, black, rich		5
Shale, thin bedded, brown, lean		2
Shale, hard, black, rich		10
Shale, thin bedded, brown, lean		3
Shale, hard, black, rich		2
Shale, thin bedded, brown, lean		4
Shale, hard, black, rich		5
	2	7

Location 103, sec. 23, T. 14 N., R. 108 W.

	Ft	in.
Shale, thin bedded, brown, lean		5
Shale, hard, black, rich	1	1
Sandstone		1
Shale, hard, black, rich	1	5
	3	0

Location 105, sec. 9, T. 14 N., R. 108 W.

	Ft.	in.
Shale, brownish, black, thin bedded, lean; not sampled	2	4

Results of distillation of samples of shale from three localities along the outcrop of a single bed in Tps. 13 and 14 N., R. 108 W., Wyoming.

Location No.	Total thickness sampled.		Yield of oil per short ton of shale.	Gravity of oil.	Yield of ammonium sulphate per short ton of shale.
	Ft.	*in.*	*Gallons.*		*Pounds.*
99	3	3½	19	Not determined.	9.3
100	2	7	34	0.8994 (25.65° B.).	5.7
103	3	0	32	.8818 (28.77° B.).	6.6

In many places massive beds of dark, tough, rich shale contain lenses of coarse sand that show no free oil. In other places small masses (some of them mere films between beds) of solid black hydrocarbon are found in the shale. Hydrocarbon occurring in this way in a small gulch east of Piceance Creek near its mouth possesses all the properties of elaterite, but in most places the material is similar to gilsonite. In sec. 14, T. 1 N., R. 97 W., this elaterite may be seen at a number of places between two beds of rather rich shale. In some places, such as Hay Gulch, in sec. 36, T. 1 N., R. 96 W., there are pockets of black material which have the shape of partly compressed stems but which show no woody structure, as would be expected if they were carbonized wood. The material contained in these pockets is not soluble in ether, chloroform, gasoline, or turpentine, the ordinary solvents of hydrocarbons.

Fossil remains, except those of microscopic size, are scarce but include leaves, fresh-water shells, insects, and fish remains. None of the fossils collected were found to be especially diagnostic, although several were identifiable. The shells were collected near the base of

the formation, as were most of the fish and leaf remains, but excellently preserved remains of insects (Diptera larvæ, etc.) were found at a number of horizons in the oil-yielding portion of the formation.

The following stratigraphic sections were measured at places indicated on the map (Pl. XVIII), and illustrate the character of the rocks exposed in different parts of the field. The beds of shale that are known by testing or are estimated to yield 15 gallons of oil or more to the ton of shale are indicated by heavy type in the sections.

Sections in northwestern Colorado.

Location A, T. 2 N., R. 104 W.

	Ft.	in.
Shale, gray, with a few hard sandstone beds each a few inches thick	350	0
Sandstone, white	1	0
Shale, gray	60	0
Sandstone, clayey	15	0
Shale, thin bedded, with a few thin beds of sandstone	15	0
Shale, brown to black, contains thin beds of rich oil shale	2	0
Shale, thin bedded, slightly carbonaceous, but is supposed to yield very little oil	30	0
Shale, brown, thin bedded, will probably yield some oil	1	0
Shale, brown, will probably yield some oil	2	0
Shale, gray, thin bedded	18	0
Shale, thin bedded, brown, contains thin laminae of oil shale	10	0
Shale, sandy	40	0
Shale, dark brown, rich in oil		4
Shale, light gray, sandy	7	0
Shale, will yield a little oil	1	0
Shale, gray	2	0
Shale, dark brown, rich in oil		4
Shale, slightly sandy	7	0
Sandstone and shale; sandstone shows ripple marks as much as 6 inches from crest to crest	15	0
Sandstone, coarse, containing concretions	3	0
Sandstone, clayey	5	0
Shale, sandy	50	0
Sandstone and shale, about 60 per cent sandstone; sandstone for the most part ripple marked; one thin bed of carbonaceous shale	90	0
Sandstone, conglomeratic at the base; most of the pebbles are flat; some are 4 inches across	2	0
Sandstone, thin bedded, not resistant	15	0
Shale, sandy	24	0
Sandstone, ripple marked; ripples 4 inches from crest to crest and three-quarters of an inch deep	3	0
Shale, sandy	10	0
Sandstone, friable, with about 10 per cent of shale; sandstone is oolitic	3	0
Sandstone, friable, with about 33 per cent of shale	54	0
Sandstone, thin bedded	15	0
Shale, gray	25	0
Sandstone, shaly	1	0
Shale, sandy	15	0
Sandstone, coarse grained	3	0
Shale	75	0
Oolite with grains as large as one-sixteenth of an inch; this stratum is a massive ledge maker, the most resistant rock of the formation	5	0
Shale, sandy	62	0
Sandstone, thin bedded	5	0
Shale, gray, mostly covered	114	0
Sandstone, thin bedded, cross bedded, and slightly conglomeratic; the grains are mostly silica and well rounded	10	0
Shale, gray	50	0
Sandstone, conglomeratic; largest pebbles obeserved have a maximum diameter of one-half inch		3
Shale, gray	26	0
Sandstone, shaly	3	0
Shale, gray	20	0
Surface covered, supposed to be mostly shale; tan-colored shale exposed at base	280	0
Sandstone, white, lenticular	3	0
Shale, drab, contains some sand	204	0
Sandstone, tan-colored		6
Shale, sandy	120	0
Sandstone, tan-colored, definitely Wasatch; bottom of section.		
	1,872	5

Sections in northwestern Colorado—Continued.

Location B, T. 1 N., R. 103 W.

	Ft.	in.
Shale, evenly thin bedded, with very little sandstone	250±	
Shale, dark, thin bedded, estimated that at least 50 per cent is oil-bearing shale (sample 10 from bed 3 feet 10 inches thick near top; 11.3 gallons)	50	0
Shale, sandy, thin bedded, lean	11	0
Sandstone		4
Shale, thin bedded, sandy in places, bituminous in others, will yield some oil	7	0
Shale, dark brown, weathers bluish gray, rich		7
Sandstone, shaly	5	0
Sandstone, friable, weathers to round forms	1	0
Shale, hard, dark brown, rich (sample 8; 4.26 gallons)	1	0
Shale, light brown (sample 8; 4.26 gallons)	3	8
Shale, alternating beds of rich oil-bearing shale (estimated 10 per cent) and lean shale	7	0
Shale, clayey, containing thin beds of rich oil shale	4	0
Shale, thin bedded	6	0
Shale and sandstone, containing some oil-bearing layers; the entire member is colored red by burning	45	0
Shale, sandy; contains some thin sandstones	5	0
Shale, sandy	10	0
Shale, dark brown, hard; weathers bluish gray; rich	1	0
Shale, clayey, thin bedded; contains a few thin layers of rich shale	19	0
Shale, sandy	3	0
Shale, thin bedded, clayey		8
Shale, sandy; contains some bituminous matter	1	0
Shale, with thin beds of rich oil-bearing shale; estimated that 50 per cent is rich rock	4	0
Shale, sandy	11	0
Shale, dark brown; weathers bluish gray; rich	2	6
Shale, sandy, thin bedded, calcareous	4	0
Shale, carbonaceous; contains beds of rich shale as thick as three-quarters of an inch (sample 12; 8.64 gallons)	2	3
Sandstone, ripple marked at top, thin bedded	7	0
Shale	3	1
Shale, lean	1	11
Shale, dark brown; contains disseminated iron sulphide (sample 11; 8.22 gallons)	1	11
Shale, thin bedded, brown		9
Shale, sandy	6	0
Shale, dark brown, massive, rich	4	0
Shale, gray, lean; contains some bituminous matter	4	0
Sandstone, thin bedded	5	0
Shale, sandy	7	0
Sandstone, even bedded	2	0
Shale, grading into sandstone at the top	7	0
Shale, dark brown, with disseminated iron sulphide, rich	1	0
Shale, sandy at base, thin bedded at top	9	0
Sandstone, thin bedded	3	0
Shale, sandy	9	0
Shale, thinly laminated, dark brown on fresh surface; contains beds of rich shale	7	0
Shale, sandy	2	0
Shale, thinly laminated, dark brown on fresh exposure; probably will yield some oil	8	0
Shale, dark brown, thin bedded, rich	1	0
Shale, sandy	13	0
Sandstone, thin bedded, ripple marked	2	0
Shale, sandy; in places will yield oil	4	0
Shale, dark brown; weathers bluish gray; rich		2
Shale, sandy	7	0
Sandstone, thin bedded, with some shale	7	0
Shale, lean	18	0
Sandstone, cross-bedded at top	3	0
Sandstone and shale	25	0
Sandstone, in beds having a maximum thickness of 4 inches	5	0
Shale, with some sandstone; shale is dark and carbonaceous; probably will yield some oil	33	0
Conglomerate; maximum size of pebbles half an inch		8
Shale, drab	25	0
Shale, brown; slight oily odor		4
Shale, dark brown; weathers blue		1½
Shale, light brown; weathers platy (sample 7; 12.6 gallons)		5
Shale, dark brown, hard; weathers blue		2
Shale, soft, brown; weathers into fine laminæ and curls on surface	1	0
Shale	50	0
Oolite		4
Sandstone and shale	25	0
Oolite		6
Shale and sandstone in layers as thick as 6 inches	40	0
Shale, finely laminated; gives slight oily odor when broken	8	0
Sandstone, calcareous		6
Shale; lower part drab; upper part weathers curly	13	0
Limestone		2
Shale, mostly drab, partly carbonaceous, finely laminated	33	0
Shale, thin bedded, rich; gives slight oily odor when freshly broken	5	0

Sections in northwestern Colorado—Continued.

Location B, T. 1 N., R. 103 W.—Continued.

	Ft.	in.
Sandstone, containing clay balls		2
Shale, drab	25	0
Shale, sandy	3	0
Sandstone, containing pebbles as large as half an inch in diameter		2
Shale, sandy	1	6
Shale, dark brown, rich; gives oily odor when broken		4
Shale, thick bedded, rich	2	10
Shale, finely laminated, brown, carbonaceous	2	6
Shale, thick bedded, rich; gives oily odor when broken	3	0
Shale	12	0
Sandstone, coarse grained		2
Shale	10	0
Sandstone		5
Shale, thinly laminated, dark brown	3	0
Talus slope at bottom.		
	929	1½

Location C, on north side of White River, T. 1 N., R. 104 W.

	Ft.	in.
Shale, sandy; weathers to round forms	50	0
Shale, light brown, lean		6
Interval, probably sandy shale	20	0
Shale, dark brown; weathers bluish gray; rich		6
Shale	7	0
Shale, dark brown; weathers bluish gray; rich	1	0
Shale	3	0
Shale, dark brown; weathers bluish gray; rich		6
Sandstone, thin bedded	15	0
Shale, dark brown; weathers bluish gray; 75 per cent rich shale and 20 per cent lean shale	8	0
Shale, dark brown; weathers bluish gray; rich		8
Shale, brown, thin bedded	1	4
Shale, dark brown; weathers bluish gray; 75 per cent rich shale and 25 per cent lean shale	5	0
Shale, dark brown; weathers bluish gray; about 10 per cent lean shale, remainder rich shale	5	0
Shale, dark brown; weathers bluish gray; about 40 per cent rich shale	35	0
Shale, dark brown; weathers bluish gray; about 10 per cent lean shale, remainder rich shale	1	0
Shale	3	0
Shale, dark brown; weathers bluish gray; about half rich shale and half lean shale	3	0
Shale, sandy	4	0
Shale, dark brown; weathers bluish gray; rich		6
Sandstone, massive	1	6
Shale, dark brown; weathers bluish gray; rich and lean shale interbedded	5	0
Shale, sandy	23	0
Sandstone, thin bedded	2	0
Shale	20	0
Shale, dark brown; weathers bluish gray; rich; contains an abundance of iron pyrite	1	0
Shale; about 25 per cent rich, dark brown	2	0
Shale, dark brown; weathers bluish gray; rich	2	0
Shale	5	0
Shale, dark brown; weathers bluish gray; rich	1	0
Shale	9	0
Shale, sandy; about 33 per cent rich, dark brown	13	0
Shale, sandy	3	0
Shale, dark brown; weathers bluish gray; rich	2	0
Shale, dark brown; weathers bluish gray; rich; and sandy shale	1	0
Shale, sandy	3	0
Shale, dark brown; weathers bluish gray; rich	1	0
Shale, drab, with thin layers of rich dark-brown shale	3	0
Shale, dark brown; weathers bluish gray; rich		6
Interval, probably mostly shale	13	0
Shale, dark brown; weathers bluish gray; rich	1	0
Shale, sandy	5	0
Sandstone	3	0
Shale	7	0
Shale, dark brown; weathers bluish gray; rich		1
Shale	4	0
Shale, dark brown; weathers bluish gray; rich	1	2
Shale	35	0
Sandstone, shaly	4	0
Shale, light gray, sandy	4	0
Shale; black; contains thin beds of rich dark-brown shale	1	0
Shale, drab, with some thin beds of rich dark-brown shale near top	20	0
Shale, dark brown; weathers bluish gray; rich; interbedded with lean shale	3	0
Shale, thin bedded; 25 per cent rich dark-brown shale	6	0
Shale, dark brown; weathers bluish gray; rich	2	2
Shale, with thin beds of rich dark brown shale		6
Shale, dark brown; weathers bluish gray; rich	1	0
Sandstone, shaly, grading to shale in the lower part	8	0

Sections in northwestern Colorado—Continued.

Location C, on north side of White River, T. 1 N., R. 104 W.—Continued.

	Ft.	in.
Shale, dark brown; weathers bluish gray; rich		1
Shale, drab	27	0
Sandstone, shaly	5	0
Shale, sandy	23	0
Shale, drab	20	0
Shale, thin bedded, black on fresh surface, rich	4	0
Shale, sandy	5	0
Shale; weathers curly; will yield some oil		6
Shale	18	0
Sandstone, shaly	5	0
Shale	8	0
Sandstone, brown		2
Shale	20	0
Shale, dark brown; weathers bluish gray; rich	1	0
Shale, gray, sandy at base, thin bedded at top	75	0
Oolite, with grains as large as one-eighth inch in diameter		5
Shale, with some rich dark-brown shale	5	0
Oolite		1
Shale, sandy, with some sandstone	13	0
Oolite		1
Shale, upper part tan-colored, lower part gray	100	0
Sandstone, light colored, with shaly layers and some rich dark-brown shale	4	0
Shale, light colored at bottom, dark at top; some rich dark-brown shale	27	0
Sandstone, including clay balls; a single fossil gastropod was found in this bed		4
Shale, drab	2	0
Sandstone, at some places oolitic and at others slightly conglomeratic		8
Shale, dark	20±	
River.		
	765	3.

Location D, T. 1 N., R. 100 W.

	Ft.	in.
Shale, drab; contains sandy layers	40	0
Shale, dark brown, rich		6
Sandstone	6	0
Shale, dark brown, rich	1	0
Sandstone, thin bedded	5	0
Shale, drab	20	0
Sandstone, thin bedded	3	0
Shale, thin bedded, lean	15	0
Sandstone; contains much crystalline quartz; weathers like an oolite		4
Shale, drab, with sandy layers	30	0
Shale, dark brown, rich	3	0
Shale, drab	35	0
Shale, lean		6
Shale, sandy	4	0
Shale; about 30 per cent rich shale in thin layers	4	0
Shale, drab	3	0
Shale, with a few streaks of rich dark-brown shale	5	0
Shale, drab	30	0
Sandstone, thin bedded	2	0
Shale and thin sandstone; contains beds as thick as 2 feet which probably will yield some oil	45	0
Shale, thin bedded, lean	10	0
Shale, drab, slightly sandy	15	0
Shale, thin bedded, lean	2	0
Shale	30	0
Shale, thin bedded, slightly carbonaceous; in places contains thin sandy beds	25	0
Covered	65	0
	399	4

Location E, T. 1 N., Rs. 99 and 100 W.

	Ft.	in.
Sandstone, yellow, slightly friable; contains concretions of pyrite	15	0
bedded	20	0
Shale; upper part slightly sandy; contains some mica; lower part not well exposed	120	0
Shale, dark gray to brown; contains a few beds of bituminous shale about half an inch thick	65	0
Shale, gray, calcareous, in beds about 2 inches thick	8	0
Shale, gray to brown, slightly bituminous	20	0
Shale, dark brown, rich		8
Shale, thin bedded, gray on weathered outcrop but contains thin beds of brown and black rich bituminous shale; estimated that 10 per cent of the rock will yield oil	18	0
Shale, dark brown, thin bedded, 75 per cent rich and 25 per cent lean	1	0
Shale; estimated 15 per cent rich oil shale	20	0
Shale, gray on outcrop; top sandy, in beds 2 inches thick	20	0
Shale, thin bedded; probably 15 per cent rich oil shale	10	0
Shale, thin bedded, papery; estimated 75 per cent rich oil shale	7	0
Shale, sandy; contains few carbonaceous layers	5	0
Shale, thin bedded, estimated 50 per cent rich oil shale	1	6
Shale; contains little rich bituminous shale, but the whole is brown on fresh surface and probably will yield oil	1	0
Shale, sandy, thin bedded	4	0
Shale, dark brown, rich		1
Shale, thin bedded, lean		6
Shale, thin bedded, dark brown, rich	2	0
Shale, sandy	2	0

Sections in northwestern Colorado—Continued.

Location E, T. 1 N., Rs. 99 and 100 W.—Continued.

	Ft.	in.
Shale, for the most part thin bedded, gray on weathered outcrop; probably 20 per cent of the whole is shale which will yield oil	13	0
Shale, dark brown, massive; resists weathering; rich	2	0
Shale, massive (estimated yield, 20 gallons)	4	0
Shale, light gray, slightly sandy and bituminous	45	0
Shale, dark brown, rich		1
Shale, thin bedded, lean	18	0
Shale (estimated yield, 20 gallons)		6
Shale, gray on weathered surface, thin bedded, lean	43	0
Sandstone, with numerous dark specks		2
Shale, sandy	7	0
Shale, dark brown; about 67 per cent rich and 33 per cent lean	1	0
Shale, drab	1	0
Shale, dark brown; appears to be very rich (sample 13; 33.6 gallons)	5	0
Shale, about 50 per cent oil shale	2	0
Shale, sandy	33	0
Shale, dark brown, rich	1	3
Shale	2	6
Shale, thin bedded, slightly carbonaceous, but will probably yield some oil		6
Shale, gray, thin bedded	15	0
Shale, dark brown, rich		6
Shale		8
Shale, dark brown, rich		6
Shale, thin bedded	4	0
Shale, dark brown, rich		2
Shale, thin bedded; contains possibly about 10 per cent rich shale	8	0
Shale, dark brown, rich	1	0
Shale		6
Sandstone, fine grained, massive		4
Shale	8	0
Shale, dark brown, rich		2
Shale, gray, thin bedded	7	0
Sandstone, shaly	2	0
Shale, sandy	7	0
Shale, dark brown, rich		8
Shale; contains some sandy beds	40	0
Sandstone, yellow, shaly	15	0
Shale and sandstone in about equal quantities	50	0
Shale, dark brown, rich		6
Sandstone, shaly		8
Shale, dark brown, rich, with some sandstone lenses	1	0
Sandstone, shaly	8	0
Shale, very thin bedded (estimated yield, 25 gallons)	1	6
Shale, 25 per cent rich	1	0
Shale, dark brown, interbedded with papery shale		6
Shale, drab	3	0
Shale, lean		3
Shale, brown, thin bedded	6	0
Shale, thin bedded (estimated yield, 15 gallons)	1	3
Shale, drab	7	0
Sandstone, shaly	2	0
Shale, dark brown (estimated yield, 25 gallons)	2	6
Shale, friable, yellow, lenticular	1	0
Shale, drab	3	0
Shale, very thin bedded (probable yield, less than 15 gallons)	2	0
Shale, sandy	3	0
Shale, thin bedded, with a few bituminous layers	10	0
Shale, dark brown, rich, thin bedded (estimated yield, 35 gallons)	3	0
Sandstone, contains quartz grains cemented with iron oxide		4
Shale, thin bedded	4	4
Shale, drab; contains sandy beds	5	0
Shale, gray, sandy	10	0
Shale, thin bedded, with some rich oil shale (estimated yield, 30 gallons)	5	0
Shale, sandy	8	0
Shale, thin bedded; will yield some oil	2	6
Shale, sandy	7	0
Shale, thin bedded, lean	5	0
Shale, drab; some layers 1 foot thick; will yield oil	10	0
Shale, dark brown, rich		4
Shale, thin bedded	4	0
Shale, brown (estimated yield, 25 gallons)	3	0
Shale, about 50 per cent bituminous	2	0
Shale, thin bedded, bituminous	7	0
Shale, thin bedded; contains rich bituminous layers; also sandstone lenses and lean shale	15	0
Sandstone, thin bedded	5	0
Shale, thin bedded (estimated yield, 15 gallons)	3	0
Sandstone, light-colored		2
Shale, dark brown; part rich and part lean	1	0
Interval largely covered, but probably shale	40	0
	874	9

Between the last bed mentioned above and the base of the Green River formation there is a distance of about 300 feet in which the rocks are largely concealed by surface material. It is probable, however, that there is considerable oil shale in this interval, but that it has been burned so as to lose its ordinary characteristics. The burning is indicated by loose fragments of red burned rock on the surface, by slaglike masses of fused material, and by black burnt-out shale exposed near the base of the formation.

Sections in northwestern Colorado—Continued.

Location F, T. 2 N., R. 98 W.

	Ft.	in.
Sandstone (about 75 per cent) and slightly bituminous shale	150	0
Shale, gray, sandy; some layers brown on fresh surfaces	45	0
Shale; about 20 per cent rich bituminous shale (samples 18, 19, 22, 23, and 24; 6.25 to 22.88 gallons)	5	0
Shale, thin bedded, slightly bituminous, and sandstone	150	0
Sandstone, minutely cross-bedded, massive	1	0
Shale, drab; contains a few thin beds of sandstone	70	0
Sandstone, massive; contains a few thin layers of conglomerate	2	4
Shale, in part slightly bituminous, with a few thin beds of sandstone	90	0
Sandstone, in part chertlike		6
Shale, thin bedded	28	0
Shale, dark brown, rich, and thin-bedded lean shale (estimated yield, 25 gallons)	5	0
Shale, sandy, lenticular	3	0
Shale, thin bedded (estimated yield, 15 gallons)	4	0
Sandstone		6
Shale, dark brown, rich (sample 21; 26.8 gallons)		11
Sandstone, cherty (sample 21; 26.8 gallons)		2
Shale, dark brown, rich (sample 21; 26.8 gallons)	3	7
Sandstone and shale	1	0
Conglomerate with pebbles half an inch in diameter		2
Sandstone and shale, with layers of rich oil shale 1 inch thick	8	0
Shale and some sandstone	8	0
Sandstone	1	0
Shale, gray, thin bedded	34	0
Sandstone, slightly conglomeratic and oolitic		8
Shale, thin bedded (estimated yield, 25 gallons)	5	0
Shale, dark brown (sample 20; 12.6 gallons)	3	0
Sandstone, irregular in thickness, weathering light yellow		9
Shale, dark brown; weathers to papery shale (sample 14; 13.3 gallons)		5
Sandstone, shaly		8
Shale, light brownish drab; weathers to sheets one-eighth to three-eighths inch thick (sample 15; 3 gallons)	1	2
Sandstone, coarse, yellow		2
Shale, light brown (sample 16; 1.9 gallons)	1	4
Shale, dark brown, fairly rich, weathers papery (sample 16; 1.9 gallons)		8
Shale, hard, dark brown; weathers to blue resistant ledges; this contains lenses of rock which weather yellow and resemble sandstone (sample 17; 21 gallons)		6
Sandstone, weathers rusty tan	9	0
Shale (80 per cent) and sandstone; some beds of shale 1 foot thick may yield as much as 15 gallons of oil to the ton	40	0
Shale (estimated yield, less than 10 gallons)	1	0
Oolite		4
Shale, slightly bituminous		½
Oolite		2
Sandstone, thin bedded	5	0
Oolite		2
Shale, slightly bituminous		¼
Oolite		3
Sandstone, thin bedded, with some bituminous shale	58	0
Shale, brown, lean, interbedded with thin sandstone	50	0
Shale, brown to black, thin bedded, slightly bituminous	50	0
Shale, brown, very thin bedded; weathers curly (estimated yield, 15 gallons)	1	0
Sandstone, shaly	15	0
Shale, brown, thin bedded; weathers curly (estimated yield, 15 gallons)	1	0
Sandstone, shaly	8	0
Shale, drab to gray, interbedded with thin beds of sandstone	90	0
Shale, brown to black, thin bedded (estimated yield, less than 15 gallons)	25	0
Shale, drab	10	0
Shale, brown on fresh surface, thin bedded, slightly bituminous		8
Shale, tan-colored; weathers white; many of the joint planes, which are at right angles to the bedding, are filled with a siliceous deposit	2	0
Shale, gray; weathers almost white; upper part thin bedded; some of the shale is slightly carbonaceous	20	0
Shale, drab and tan-colored	100	0
Sandstone, light gray, fine grained, calcareous, ripple marked, lenticular	8	0
Shale, drab and tan-colored	200	0
Sandstone, ripple marked, lenticular	1	0
Shale, sandy	15	0
Sandstone, tan-colored, thin bedded	1	0
Shale, drab	28	0
Shale, tan-colored	50	0
Oolite		6
Shale, tan-colored	20	0
Sandstone, thin bedded		6
Shale, drab, thin bedded	40	0
Sandstone, tan-colored, ripple marked, thin bedded	1	0
Shale, with a few sandstone beds, tan colored; Wasatch formation	200	0
	1,677	1¾

Sections in northwestern Colorado—Continued.

Location G, T. 2 N., R. 97 W.

	Ft.	in.
Top of hill.		
Sandstone, massive, tan-colored, slightly friable, fairly coarse grained, weathers into nodular forms	5	0
Shale, sandy	300±	
Shale, dark brown, rich		½
Shale, sandy	30	0
Shale, dark brown (probable yield, 10 gallons)	1	0
Shale, drab, thin bedded	50	0
Shale (estimated yield, 20 gallons).	3	0
Shale, thin bedded, sandy	25	0
Shale, dark brown, rich	1	0
Shale, sandy	45	0
Sandstone	3	0
Shale	5	0
Shale, dark brown, rich		½
Shale, sandy	100	0
Shale (estimated yield, 25 gallons)	3	0
Shale, drab, with some sandy beds, lean.	60	0
Shale, generally lean, but with some rich layers	1	0
Shale (80 per cent) and sandstone (20 per cent)	20	0
Shale, thin bedded, containing thin layers of rich shale (probable yield of the whole, 15 gallons)	5	0
Shale, drab, with some sandy layers	20	0
Shale, sandy	10	0
Shale, dark brown, with some lean beds (estimated yield of the whole, 25 gallons)	2	0
Sandstone, shaly	1	0
Shale, dark brown (estimated yield, 20 gallons)	2	0
Shale, lean, oolite, and sandstone, intimately interbedded; oolite and sandstone lenticular	3	0
Sandstone, shaly	3	0
Shale, drab	4	0
Sandstone	7	0
Sandstone, shaly	10	0
Shale, with some thin beds of sandstone; part of the shale is carbonaceous; other parts will probably yield a little oil	40	0
Interval, mostly covered but probably shale	50	0
Shale, thin bedded (estimated yield, 15 gallons)	2	0
Shale, carbonaceous, containing beds as thick as 6 inches which will yield oil	20	0
Shale, sandy	15	0
Shale (estimated yield, 25 gallons)	5	0
Shale (estimated yield, 20 gallons)	2	0
Shale, thin bedded, mostly carbonaceous; some parts are flexible and probably will yield oil; benches as thick as 2 feet are estimated to yield 25 gallons.	30	0
Shale, sandy, in places carbonaceous	25	0
Shale, for the most part drab and thin bedded; contains beds as thick as 1 foot which will probably yield 20 gallons	30	0
Shale, 10 per cent dark brown, rich and 90 per cent lean	2	0
Shale, thin bedded (possible yield, 15 gallons)	10	0
Shale, carbonaceous	3	0
Covered, probably mostly shale	100	0
Shale, curly; contains lenses of bituminous sandstone (samples 25 and 26, lower 8 feet of this bed; 4.78 and 3.85 gallons)	15	0
Shale, carbonaceous and sandy	2	0
Sandstone		4
Shale, thin-bedded, carbonaceous; will probably yield a small quantity of oil.	3	0
Interval, probably mostly lean shale but with a few thin beds which are rich in oil	60	0
Shale, thin bedded (estimated yield, 15 gallons)	3	0
Sandstone		½
Shale, thin bedded, black on fresh surface (estimated yield, 25 gallons).		8
Interval, covered, probably shale	6	0
Shale, dark gray to black, thin bedded (estimated yield, 25 gallons)	3	0
Interval, mostly covered but probably sandy shale	20	0
Oolite		10
Shale, thin bedded, brown on fresh surface, with sandstone beds as thick as 1 foot near the base (top includes beds estimated to yield less than 15 gallons)	15	0
Shale, thin bedded, brown on fresh surface; contains lenses of sandstone	4	0
Interval, covered but probably shale	15	0
Sandstone and sandy shale; the sandstone, especially in the upper part, is oolitic	13	0
Sandstone, mostly friable; contains beds which weather rusty	15	0
Shale	3	0
Sandstone and oolite	3	0
Sandstone, friable	2	0
Shale, upper part sandy, lower part slightly carbonaceous in places	15	0
Oolite and sandy shale	3	0
Sandstone, shaly	8	0
Sandstone, with oolitic phases	3	0
Sandstone, shaly, friable	3	0
Oolite	17	0
Sandstone, friable	10	0
Oolite	20	0
Sandstone, shaly	15	0
Shale and sandstone, folded and faulted to such an extent that detailed measurements are not possible. The folding and faulting are believed to be confined to this member. Some of the shale will probably yield oil	100	0
Sandstone, tan-colored, slightly cross-bedded; contains oolitic layers near the top	17	0

Sections in northwestern Colorado—Continued.

Location G, T. 2 N., R. 97 W.—Continued.

	Ft.	in.
Sandstone, friable; contains a few thin lenses of oolite near the base	15	0
Sandstone, with lenses of oolite averaging about 2 inches long	1	0
Sandstone, shaly; cut by normal faults having throws of 6 to 8 feet; fault planes dip about 50° S.; ripple marks were noted in the highest and lowest layers of the bed	3	0
Interval, mostly covered, probably sandy shale	40	0
Sandstone; contains oolitic phases	5	0
Sandstone, shaly	1	0
Sandstone, oolitic	5	0
Sandstone, shaly	3	0
Sandstone, minutely cross-bedded; top oolitic	5	0
Sandstone, shaly	1	0
Oolite	15	0
Sandstone, oolitic	2	0
Shale, sandy, but contains carbonaceous beds, also sandstone layers as thick as 2 inches	25	0
Oolite, containing numerous gastropods at the base	8	0
Sandstone, shaly at the base, gray on unweathered surface	3	0
Shale, slightly gray, sandy	4	0
Sandstone, with numerous gastropods	1	0
Sandstone, massive, slightly cross-bedded, fairly well rounded grains of quartz	4	0
Sandstone, calcareous, contains gastropod remains		6
Sandstone, massive, slightly cross-bedded	15	0
Sandstone; weathers buff; resistant, in layers 1 inch to 6 inches	1	6
Shale, sandy, and friable sandstone; the sandstone predominates but does not form ledges. This is supposed to be typical Wasatch.		
	1,605	11½

Section near location H, from gas well to mouth of Piceance Creek, T. 1 N., R. 97 W.

	Ft.	in.
Sandstone, coarse, yellowish brown, friable, cross-bedded	169	0
Shale, light gray	10	0
Sandstone, tan-colored, friable	20	0
Sandstone, brown, friable	160	0
Shale, light gray, sandy (sample 42; 0.31 gallon)	45	0
Shale, gray, thin bedded	12	0
Shale, hard, brown, rich, lenticular	1	0
Shale, gray	73	0
Sandstone, yellowish brown at base, contains vegetable remains	55	0
Shale, with few lenses of sandstone, much distorted	40	0
Shale, sandy, very lean	5	0
Shale, sandy at base	60	0
Shale, sandy at top	24	0
Shale, hard, brown, rich		3
Shale, sandy	25	0
Shale, sandy, thin bedded	2	6
Shale, lean (90 per cent) and hard, rich shale (10 per cent)	1	6
Shale, sandy, thin bedded, gray	3	0
Sandstone, massive, yellowish brown, coarse grained	17	0
Sandstone, yellowish, thin bedded	12	0
Shale and thin beds of rich, hard shale	32	0
Shale, sandy, thin bedded	17	0
Shale, hard, rich, and thin-bedded shale	3	0
Shale, sandy	10	0
Shale, hard, brown, rich		1
Shale, sandy, thin bedded	30	0
Shale, for the most part barren but including beds as thick as 1 foot which will yield considerable oil	132	0
Sandstone, clayey	5	0
Shale, hard, brown, lean	3	0
Sandstone, clayey, shaly	17	0
Shale, sandy (80 per cent), and hard, rich shale (20 per cent)	2	6
Shale, hard, brown (sample 38; 25.2 gallons)	5	11
Shale, slightly sandy	10	0
Sandstone, calcareous	3	0
Shale, partly rich and partly curly	3	0
Shale, top sandy, tan-colored	80	0
Shale, hard, brown, rich (90 per cent) and lean shale (10 per cent)	2	0
Shale, thin bedded, carbonaceous, sandy	3	0
Shale, curly, lean (75 per cent), and hard, rich shale (25 per cent)	3	4
Shale, sandy	5	0
Shale, curly, lean	2	0
Shale, drab		6
Sandstone, irregularly bedded		2
Shale, thin bedded, lean	10	0
Shale, thin bedded, lean (90 per cent), and hard, rich shale (10 per cent)		6
Shale, thin bedded, sandy	5	0
Shale, thin bedded (90 per cent), and hard, rich shale (10 per cent)	1	0
Shale, slightly curly, lean	5	0
Sandstone, clayey	1	0
Shale, thin bedded at base, sandy at top	25	0
Shale, hard, rich		6
Shale, sandy	2	0
Sandstone, calcareous	5	0
Shale, thin bedded, curly	1	0
Shale, hard, brown, variable thickness (sample 37; 23.25 gallons)	5	8½
Shale, thin bedded	20	0

Sections in northwestern Colorado—Continued.

Section near location H, from gas well to mouth of Piceance Creek, T. 1 N., R. 97 W.—Continued.

	Ft.	in.
Shale.curly, and hard, rich shales		10
Shale, brown, thin bedded, lean	3	0
Shale, sandy, thin bedded	15	0
Shale, thin bedded, curly	1	0
Shale, sandy		5
Shale, thin bedded, slightly curly	1	0
Shale, hard, brown, rich	2	0
Shale, brown, lean		10
Shale, thin bedded, slightly carbonaceous	10	0
Shale, hard, rich		6
Shale, black, carbonaceous, lean	2	0
Shale, thin bedded, drab	18	0
Shale, hard, rich (50 per cent), and lean shale (50 per cent)	2	0
Shale, slightly curly (95 per cent), and rich shale (5 per cent)	1	0
Shale, sandy	100	0
Shale, hard, rich, and lean shale (estimated yield, 30 gallons)	3	0
Shale, thin bedded, lean	5	0
Shale, massive, rich, weathers bluish	5	0
Shale, thin bedded, lean (90 per cent), and rich shale (10 per cent)	52	0
Shale, dark brown, rich, and lean shale (50 per cent each)	16	0
Shale, hard, dark brown, rich	5	0
Shale, drab	2	0
Shale, thin bedded, lean	3	0
Shale, weathers blue; massive, rich (samples 32, 33, 34, 35, and 36; 14.7 to 40.6 gallons)	5	0
Shale, thin bedded, lean	31	0
Shale, hard, dark brown, rich	3	0
Shale, hard, black, rich	1	0
Shale, thin bedded, lean	28	0
Shale, hard, dark brown; estimated yield, 15 gallons	1	0
Shale, light gray	2	0
Shale, curly; will yield oil	1	6
Shale, dark brown, hard, rich		3
Shale, sandy, carbonaceous	3	4
Shale, curly, papery, and small lenses of solid hydrocarbons	2	0
Shale, dark brown, hard, rich		4
Shale, drab	37	0
Shale, partly papery, curly, with a few thin one-half inch beds of hard, dark-brown, rich shale	35	0
Shale, curly, papery; will yield oil	40	0
Shale, dark brown, thin bedded	3	4
Shale, sandy	1	0
Shale, brown, curly, with lenses of sandstone	5	0
Sandstone, lenticular (Sample		2
Shale, thin bedded 31; 15.5	1	2
Shale, light brown, lean. gallons).		8
Shale, very dark brown, curly, thin bedded		8
Shale, thin bedded brown		8
Shale, curly	4	4
Shale, curly papery; will yield oil	20	0
Covered, mostly shale	30	0
Shale, curly, papery, will yield oil	3	0
Covered, probably mostly shale	15	0
Shale, dark brown, rich		1
Shale, much of it papery, curly; will yield a small amount of oil	154	0
Shale, curly, papery, fairly rich (samples 27, 28, 29, and 30; 8.4 to 12.5 gallons)	15	0
Shale, much of it curly and will yield oil	67	0
Shale, curly, papery; will yield oil	8	0
Shale and clay, tan	48	0
Oolite	1	0
Shale, sandy at base	40	0
Oolite	3	0
Sandstone	42	0
Sandstone, ripple marked at top, with lenses of oolite	22	0
Shale, sandy	5	0
Oolite, massive; weathers brown	3	0
Sandstone	8	0
Sandstone, oolitic at base, thin bedded at top	7	0
Oolite	2	0
Sandstone	41	0
Sandstone, brown, fossiliferous (gastropods)	2	0
Sandstone, massive, irregular base, ripple marked on top	5	0
Covered, but probably tan-colored shale	83	0
Sandstone, resistant and cross-bedded at top, friable near base	27	0
Sandstone, light gray to white, coarse	3	0
Sandstone, clay, and varicolored lenticular shale	200	0
	2,496	6½

Location I, north of White River, T. 1 N., R. 96 W.

	Ft.	in.
Sandstone, ripple marked	25	0
Sandstone and shale	189	0
Sandstone, conglomeratic, friable, yellow	15	0
Shale, yellow	58	0
Shale, drab	1	0
Shale, brown, lean	1	0
Shale, drab, with thin beds of rich shale	2	0
Shale, thin bedded, curly	1	0
Shale, drab	1	0
Shale, lean (25 per cent), and rich **shale** (75 per cent)	1	0
Shale, sandy	4	0
Shale, dark brown, massive, rich	1	0
Sandstone, friable		6
Shale, thin bedded, and lean brown shale	4	0
Sandstone, oolitic, tan-colored	1	0
Shale, gray, thin bedded	15	0
Sandstone, oolitic and conglomeratic	3	0

Sections in northwestern Colorado—Continued.

Location I, north of White River, T. 1 N., R. 96 W.—Continued.

	Ft.	in.
Shale, gray, thin bedded	35	0
Shale and sandstone, lean	77	0
Sandstone, friable	4	0
Shale, sandy	2	0
Shale, curly (estimated yield, not more than 10 gallons)	5	0
Interval	24	0
Sandstone, oolitic, ripple marked	3	0
Shale and sandstone, lenticular	167	0
Sandstone, oolitic and oolite	10	0
Shale and thin beds of sandstone	85	0
Shale, brown, curly	5	0
Sandstone, friable, lenticular	10	0
Shale, sandy, drab	47	0
Shale, thin bedded	3	0
Shale, sandy, drab	75	0
	874	6

Location J, T. 1 N., R. 96 W.

	Ft.	in.
Shale, gray; probably will yield little or no oil	200	
Shale, containing a few thin beds of rich black shale	20	0
Shale; contains a large number of rich layers interbedded with sandy shale	20	0
Shale, thin bedded; contains a large number of thin beds of rich shale; the whole slightly richer than the unit next above	15	0
Shale, hard, dark brown, rich		6
Shale; contains a few thin beds of rich shale	8	0
Shale, hard, dark brown, rich		2
Shale, thin bedded, slightly sandy	2	0
Shale, hard, dark brown, rich (sample 41; 13.7 gallons)	1	4
Shale, lean	2	0
Shale, hard, brown, massive (sample 40; 12.5 gallons)	3	8
Shale, interbedded with layers of rich shale; the whole probably lean	6	0
Shale, thin bedded, slightly sandy	15	0
Shale, hard, dark brown, rich		4
Shale, thin bedded	5	0
Shale, hard, dark brown, rich		10
Shale, sandy	5	0
Shale, hard, dark brown, rich	1	0
Sandstone		8
Shale, hard, dark brown, rich with some lean layers	3	0
Shale, thin bedded, slightly sandy	50	0
Shale, hard, dark brown, rich		8
Shale, thin bedded, slightly sandy; containing caverns in places filled with solid hydrocarbon	5	0
Shale, sandy	7	0
Shale, lean	1	0
Shale, hard, dark brown, rich	1	0
Shale, thin bedded, slightly sandy	5	0
Shale, hard, dark brown, rich	1	0
Shale, lean, slightly sandy	2	0
Shale, sandy, thin bedded	11	0
Shale, sandy; contains a few thin layers of rich shale	5	0
Shale, gray, slightly sandy	4	0
Shale, hard, dark brown, rich, with lean shale interbedded	1	10
Shale, gray, slightly sandy	8	0
Shale, lean		6
Shale, sandy	3	4
Sandstone, tan-colored		4
Shale; probably will yield a small amount of oil		10
Shale, gray	6	0
Shale, hard, dark brown, rich	2	0
Shale, papery, lean	3	0
Shale, sandy		5
Shale, dark brown, rich		½
Shale, lean		7
Shale, rich		8
Shale, gray, slightly sandy	10	0
Shale, hard, dark brown, rich		6
Shale, lean	6	0
Shale, very lean	1	0
Shale, sandy	5	0
Shale, dark brown, rich		1
Shale, lean	1	6
Shale, hard, dark brown, rich		3
Shale, lean		10
Shale, dark gray, thin bedded, lean		6
Shale, gray, slightly sandy	5	0
Shale, brown to black, thin bedded, rich	3	0
Shale, brown to black, thin bedded, probably lean	2	0
Shale, sandy, thin bedded	3	6
Shale, dark brown to black, thin bedded, lean	2	10
Shale, dark brown to black, thin bedded to almost papery, lean	1	6
Shale, hard, dark brown, rich		2
Shale, drab, thin bedded, sandy	5	0
Sandstone, massive, showing slight ripple marks	3	0
Shale, sandy	8	0
Sandstone, massive, resistant	2	0
Shale, gray, thin bedded	3	0
Sandstone		4
Shale, gray, thin bedded	45	0
Sandstone, massive, cross-bedded	15	0
Shale, gray, thin bedded	5	0
Shale, dark gray to black, probably lean	1	0
Shale, gray, thin bedded, with thin beds of sandstone	25	0
Shale, hard, dark brown, rich		3
Shale, weathers gray, lean	1	0
Shale, gray, thin bedded	12	0
Shale, thin bedded, dark brown to black on fresh surface (sample 39; 13.7 gallons)	3	0
Shale, hard, brown, probably rich		6

Sections in northwestern Colorado—Continued.

Location J, T. 1 N., R. 96 W.—Continued.

	Ft.	in.
Shale, thin bedded, lean		8
Shale, hard, dark brown, rich		3
Sandstone, with numerous fragments of vegetable remains	2	0
Shale, gray, sandy, with thin beds of lean shale	10	0
Sandstone, coarse grained, conglomeratic, containing flat pebbles of shale.	1	0
Shale and sandstone; much of the surface covered	45	0
Sandstone, conglomeratic, tan-colored; contains flat pebbles of shale as long as 4 inches and as thick as one-quarter inch	3	0
Sandstone, tan-colored, massive, slightly friable, minutely cross bedded	35	0
Shale, drab, sandy	55	0
Sandstone	1	0
Sandstone and shale, fossiliferous	30	0
Sandstone, tan-colored on weathered surface, minutely cross-bedded	2	0
Shale, sandy; one fossil leaf was found in this member	5	0
	1,666	10½

Location K, on north side of Fourteenmile Creek, T. 3 S., R. 95 W.

	Ft.	in.
Sandstone, brown, massive	50	0
Shale, light brown	75	0
Shale, thin bedded, light brown, lean (sample 44; 6.2 gallons)	64	0
Sandstone, shaly	19	0
Shale, thin bedded; weathers light gray; probably as rich as the bed from which sample 43 was taken	40	0
Sandstone, shaly	17	0
Shale, thin bedded; weathers light gray; probably as rich as the bed from which sample 43 was taken	59	0
Shale, dark brown, but probably not rich		3
Shale, thin bedded, very hard, black	1	5
Shale, brown, hard, probably lean		7
Shale, very dark brown, hard	1	6
Shale, dark brown, containing small lenses of sandstone	1	0
(sample 43: 9.4 gallons).		
Sandstone, irregular in thickness		2
Shale, lean (80 per cent), and rich, brown shale (20 per cent)	35	0
Shale, light brown; weathers white; lean.	7	0
Interval, probably mostly shale	40	0
Shale, gray	110	0
Shale, thin bedded, light colored	10	0
Shale, dark drab, thin bedded	28	0
Shale, very thin bedded, with thin layers of rich, dark-brown shale	1	0
Shale, gray, lean; weathers to small plates	5	0
Shale, thin bedded, lean	11	0
Sandstone, coarse grained, irregular bedded		6
Shale, bluish gray	11	0
Sandstone, fine grained		8
Shale, bluish gray; contains vegetable remains	12	0
Sandstone, brown, shaly	10	0
Shale, gray, with a few thin beds of rich shale	117	0
Sandstone, grayish brown		8
Shale, drab, platy; contains stems of wood and pockets of solid hydrocarbon.	65	0
Sandstone, gray	4	0
Shale, gray	17	0
Sandstone, brown	1	0
Shale, gray	2	0
Sandstone, brown	1	0
Shale, gray, clayey	77	0
Sandstone, coarse, yellow	7	0
Shale, drab; contains wood fragments	80	0
Sandstone, coarse, angular grains, yellow.	2	0
Shale, gray	5	0
Sandstone, brown, coarse	1	0
Shale, light drab	15	0
Sandstone, coarse, yellowish brown	3	0
Shale, light drab, very clayey	53	0
Sandstone, yellowish brown, ripple marked	1	6
Shale, drab, sandy, with three thin beds of brownish sandstone	32	0
Sandstone, yellowish brown, upper part oolitic; contains rounded quartzite pebbles	19	0
Top of Wasatch formation.		
	1,113	

Location L, on Piceance Creek, T. 4 S., R. 94 W.

	Ft.	in.
Sandstone, brown, massive	150±	
Shale, sandy; weathers light gray	95	0
Shale, dark brown, hard; weathers gray; lean	112	0
Shale, hard, dark brown, rich		5
Shale, dark brown, hard; weathers gray (probable yield, less than 15 gallons)	11	0
Shale, hard, black; weathers bluish (estimated yield, 25 gallons)	2	0
Shale, dark brown, hard; weathers gray; lean	40	0
Shale, hard, dark brown (estimated yield, 30 gallons)	1	0
Shale, dark brown; weathers gray; lean	168	0
Shale, dark brown, rich, and thin-bedded shale	2	0
Shale, brown; weathers gray; with a few thin beds of hard, dark-brown, rich shale	38	0

Sections in northwestern Colorado—Continued.

Location L, on Piceance Creek, T. 4 S., R. 94 W.—Continued.

	Ft.	in.
Sandstone, shaly; weathers reddish brown	90	0
Shale, drab	100	0
Sandstone	4	0
Shale	18	0
Sandstone	3	0
Shale, drab, slightly sandy	523	0
Shale, bluish drab, with about 5 per cent of beds of sandstone 5 inches thick	102	0
Shale, drab, slightly sandy, interbedded with layers of sandstone 1 foot thick	120	0
Sandstone, brown, coarse grained	8	0
Shale, drab, slightly sandy, with about 8 per cent of sandstone in beds 4 inches thick	60	0
Sandstone, brown	10	0
Shale, drab, somewhat sandy, interbedded with about 20 per cent of sandstone in beds 8 inches thick	65	0
Sandstone, brown	8	0
Shale, drab, sandy, with about 40 per cent of sandstone in beds 1 foot thick	45	0
Sandstone, gray	15	0
Sandstone in beds averaging 6 feet thick, interbedded with gray sandy shale (shale probably 50 per cent of the whole)	200	0
Sandstone, massive, brown	12	0
Sandstone and gray shale, Wasatch.		
	2,002	5

Location M, on north side of Pole Gulch, T. 4 S., R. 94 W.

	Ft.	in.
Shale, light brown, weathers gray; contains a few thin beds of rich shale	75	0
Shale, black, massive; weathers dark blue; rich	1	0
Shale, light brown; weathers gray; contains several thin beds of sandstone, also thin beds of rich shale	17	0
Shale, dark brown, rich		8
Shale, light brown, weathers gray; will yield a small quantity of oil	25	0
Shale, brown (sample 46; 12.5 gallons)	5	2
Shale, gray, lean	5	0
Shale, brown, probably not quite as rich as the bed from which sample 46 was taken	4	6
Shale, light brown; will yield a small quantity of oil	5	0
Shale, brown, weathers thin bedded, curly (estimated yield, 15 gallons)	2	0
Shale, light brown, with beds of rich shale (probable yield less than 10 gallons)	11	0
Shale, dark-brown, weathers blue	1	1
Shale, very light brown; weathers yellowish gray; will yield very little oil	15+	
	167	5

Location N, on the face of a cliff southwest of Cook's ranch, T. 4 S., R. 94 W.

	Ft.	in.
Top of cliff approximately 1,400 feet above the base of the Green River formation.		
Shale, thin bedded; weathers platy; lean.	15	0
Shale, dark brown, rich; weathers bluish gray and thin bedded		6
Shale, light brown; weathers yellow; probably will yield a small quantity of oil	3	0
Shale and thin sandstone bed	5	0
Shale, lean	3	6
Shale, yellowish gray; will yield but little oil	5	0
Shale, light brown; weathers to thin laminæ (sample 49; 10.5 gallons)	3	0
Shale, yellowish gray, probably very lean.		7
Shale, dark brown, rich		6
Shale; weathers gray; probably will yield a small quantity of oil	7	0
Shale, dark brown, rich (sample 48; 15.5 gallons)	4	0
Shale and thin-bedded sandstone; will probably yield a little oil	5	0
Shale, brown, lean	2	0
Shale, light gray	6	0
Shale, dark brown, rich; weathers bluish gray		5
Shale, lean (estimated yield, 10 gallons)	2	0
Shale, light brown, very lean	4	0
Shale, dark brown, rich		1
Shale		3
Shale, dark brown, rich		1
Sandstone, irregularly bedded		2
Shale, dark brown, rich, containing much pyrite		2
Shale, gray and thin sandstone	10	0
Shale, dark brown, rich; weathers bluish gray		1
Shale, lean	11	0
Shale, hard, dark brown; weathers bluish gray; contains a large amount of pyrite	10	0
Shale, gray (may yield as much as 10 gallons)	11	0
Shale, thin bedded (may yield as much as 15 gallons)		8
Shale, weathers white	16	0
Shale; weathers bluish (will not yield more than 10 gallons)		10
Shale, dark brown, rich; weathers blue; contains a large amount of pyrite		3
Shale and sandstone	6	0
Shale; weathers white		1
Sandstone		3
Shale; weathers white; lean	1	6
Sandstone		3
Shale; weathers white; will yield a little oil	1	8
Shale; weathers bluish, thin bedded (sample 47, 7 gallons)	2	0
Shale; will yield a little oil	2	6
Talus slope concealing the lower rocks.		
	141	4

Sections in northwestern Colorado—Continued.

Location O, in Book Cliffs north of Morris station, T. 6 S., R. 94 W.

	Ft.	in.
Shale, brown, makes the upper part of the cliff; probably will yield considerable oil but could not be examined	210±	
Shale, weathers thin bedded; black to bluish gray (sample 50; 40.6 gallons)	10	0
Shale (probably will yield less than 15 gallons)	25	0
Shale, hard, black, rich.	2	0
Sandstone (excluded from sample) (sample 51; 28 gallons).		2
Shale, light brown, very hard	1	10
Shale, black, hard; appears to be very rich		5
Shale; weathers white; thin bedded, slightly carbonaceous; contains a few thin beds of rich shale, also sandstone lenses	40	0
Shale, light yellow, thin bedded, sandy	30	0
Sandstone, coarse grained	2	0
Shale; weathers white; contains some sandy beds	40	0
Shale, rich, dark brown		1
Shale, slightly sandy, thin bedded	1	0
Shale, rich, dark brown		3
Shale, slightly sandy, gray	1	0
Shale, dark brown, rich		8
Shale, lean		6
Shale, mostly gray, partly sandy, contains a few beds of curly shale; the whole is supposed to be very lean	75	0
Shale, with some sandstone beds as thick as 2 feet	120	0
Sandstone, tan-colored, coarse grained	25	0
Shale, dark brown, rich		3
Sandstone (90 per cent) and shale (10 per cent); sandstone coarse grained, cross-bedded, and conglomeratic in lower part	25	0
Shale (90 per cent) and sandstone (10 per cent); this member contains beds of sandstone as thick as 8 feet; shale is in places slightly carbonaceous	100	0
Sandstone, light tan-colored to gray, very persistent in thickness	5	0
Sandstone (25 per cent) in beds not over 8 inches thick, and drab shale (75 per cent)	25	0
Oolite (50 per cent) and thin-bedded carbonaceous shale (50 per cent); contains fish scales	2	0
Sandstone (10 per cent) and shale (90 per cent); some of the sandstone beds are as thick as 5 feet and are conglomeratic	60	0
Shale, drab; contains a few thin beds of sandstone	60	0
Shale (90 per cent), in places thin bedded and slightly carbonaceous, and sandstone, in part ripple marked (10 per cent)	70	0
Sandstone (50 per cent) and gray shale, in part clayey (50 per cent); sandstone at top is even bedded and appears persistent; that in the lower part is irregular in thickness	100	0
Shale, for the most part gray (75 per cent) and thin-bedded sandstone (25 per cent)	300	0
Sandstone and shale; sandstone beds are massive, tan-colored for the most part and cross-bedded; shale in the lower part of the member is yellow and is similar to Wasatch. At the base of the member is a bed of massive sandstone 10 feet thick with 15 feet of thin-bedded sandstone above. These beds are irregular in thickness and look like the typical Wasatch	750	0
Variegated clays and shales with sandstone lenses at irregular intervals.		
	2,082	2

Location P, in upper part of Book Cliffs north of Rulison, Colo., T. 6 S., R. 95 W.

	Ft.	in.
Shale, massive, probably will yield considerable oil; forms at this locality impassable cliff	100±	
Shale, light brown (sample 56; 11.2 gallons)	15	0
Shale brown, probably richer than that of the bed above	100	0
Shale, dark brown (sample 55; 15.4 gallons)	13	0
Shale, probably as rich as that above	20	0
Sandstone, shaly	10	0
Shale, probably fairly rich in oil	35	0
Shale, thin bedded; weathers black; inclined to be curly (to be correlated with the bed from which sample 50 was taken; see above)	6	0
Shale; weathers yellowish; lean	25	0
Shale, dark brown; weathers gray (sample 54; 20.7 gallons)	8	0
Talus slope.		
	332	0

Sections in northeastern Utah.

Location Q, along Evacuation Creek between Temple switch and Dragon, Utah.

	Ft.	in.
Shale, thin bedded, lean to barren	40	0
Shale, hard, dark (estimated yield, 20 gallons)	1	0
Shale, lean to barren, thin bedded; a few rich layers less than 1 inch thick (Diptera larvæ)	155	0
Sandstone	1	0
Shale, platy, lean to barren; two or three rich beds about 1 inch thick	36	0
Shale, thin bedded, rich	1	0
Shale, lean	6	0
Sandstone, persistent		5
Shale, lean, thin bedded	4	0
Shale, hard, dark brown, rich	1	10
Shale, hard, light brown, rich	2	1
Shale, hard, dark brown, rich		6
Shale, sandy (not in sample)		
Shale, hard, dark brown, rich		2
Shale, hard, light brown, rich		3
Shale, hard, dark brown, rich		10
		8
(sample 68; 31 gallons).		
Shale, dark, tough	1	4
Shale, dark, platy	1	5
Shale, hard, dark, rich		2½
Shale, soft, dark brown		3
Shale, hard, dark, rich		3
Shale, soft, dark brown		5
(sample 67, from richest part of upper bench; 90 gallons. Sample 65, from whole bed at at surface; 32 gallons.)		
Shale, hard, dark, rich		3½
Shale, soft, dark brown		10
Shale, hard, dark, rich	1	6
(sample 66 from whole bed 1½ feet back from outcrop; 55 gallons.)		
Shale, thin bedded, platy	4	2
Shale, rather lean and papery	2	0
(sample 66; 15 gallons.)		
Shale, hard, dark brown to black (sample 63; 32 gallons)	4	3
Shale, hard, lean, some thin sandstone layers	3	10
Shale, hard, rich (samples 58 and 62; 23 and 18 gallons, respectively)	3	11
Shale, minutely banded, some rich layers (sample 61; 10 gallons)	6	7
Shale, lean to barren, with two bands of small dark sandstone lenses	4	0
Sandstone, hard, quartzitic, persistent		5
Shale, sandy, barren; thin beds of sandstone	3	1
Shale, brown and black, rich		7
Shale, hard; weathers green		
(sample 60; 12 gallons).		

	Ft.	in.
Shale, sandy; weathers greenish gray; lean to barren	2	0
Shale, hard (sample 59; 9 gallons)	1	0
Sandstone, rough, coarse, containing asphalt; top and bottom surfaces irregular, with shale conforming to the irregularities	1	10
Shale	7	0
Sandstone, persistent		3
Shale, lean, sandy, gray to reddish, with several thin layers of sandstone	13	8
Shale, hard, rich	2	0
Shale, soft	2	0
Shale, hard, rich	1	9
(sample 74; 32 gallons).		
Sandstone		3
Shale, hard		3½
Sandstone (not included in sample)		1½
Shale, hard	1	7
Sandstone, persistent (not included in sample)		2
Shale, hard		11
Shale, clayey		5
Shale, hard, mostly lean, with thin beds of richer shale	1	6
(sample 73; 6 gallons).		
Sandstone, persistent		3
Shale, hard, rich	2	9
Sandstone		1
Shale, hard, rich		11
Sandstone		½
Shale, hard, rich	2	6
(sample 72; 7 gallons).		
Sandstone		2
Shale, hard, dark (sample 71; 7 gallons)	7	0
Sandstone, persistent		6
Shale, hard, rich to lean	3	3
Horizon of sandstone lenses, none of which came where sample was taken.		
Shale, hard, rich	2	6
(sample 70; 14 gallons).		
Sandstone		1
Shale, probably, lean		7
Sandstone, bearing gypsum (not included in sample)		5
Shale, hard, dark, rich; some gypsum near top	1	10
Shale, with considerable gypsum		4
Shale, very dark brown, rich		5
(sample 69; 19 gallons).		
Sandstone, brownish, shaly	23	0
Shale, papery, lean	1	6
Shale, rich; weathers blue		6
Shale, sandy, and barren shaly sandstone	10	0
Shale, rich, papery		6
Shale, sandy, barren	17	6
Sandstone, brown, massive		11

Sections in northeastern Utah—Continued.

Location Q, along Evacuation Creek between Temple switch and Dragon, Utah—Continued.

	Ft.	in.
Shale, lean to barren	2	6
Sandstone, massive, ledge making	5	0
Sandstone, brownish, shaly	50	0
Shale, forming ledge, lean to rich	4	6
Shale, papery, lean to barren	4	0
Shale, hard, rich		3
Shale, sandy, lean to barren; two or three sandstone ledges less than 1 foot thick	43	0
Shale, papery; numerous thin blue rich bands	7	0
Shale, barren, with several brownish sandstone layers 2 to 4 inches thick	20	0
Shale; weathers bluish; rich, ledge forming	1	0
Shale; weathers bluish; barren	2	7
Sandstone, light brown	1	0
Shale; weathers bluish; barren	1	5
Sandstone, light brown	4	0
Shale; weathers bluish; barren	1	6
Sandstone, light brown		8
Shale; weathers bluish; barren	1	3
Sandstone, massive	2	6
Sandstone, gray, shaly	3	0
Sandstone, yellowish brown, not well cemented	48	0
Shale, gray	35	0
Sandstone	4	0
Shale, gray	7	0
Sandstone	2	0
Shale, drab	13	0
Oolite	6	0
Shale, drab	42	0
Oolite	2	4
Shale, gray	4	0
Oolite	3	10
Shale, gray	14	6
Sandstone, massive cross-bedded	14	0
Shale, drab	6	0
Sandstone, massive	8	6
Shale, gray and drab	28	0
Sandstone, resistant		10
Shale, drab	4	0
Sandstone, massive	23	0
Shale, drab	11	0
Sandstone, massive	4	6
Shale, drab to green	17	0
Oolite, much distorted	2	8
Shale, gray	1	0
Oolite, much distorted	8	6
Shale, sandy	19	0
Oolite	3	0
Sandstone, massive	7	0
Oolite	1	2
Sandstone, massive for the most part; some oolitic members near base	61	0
Shale, drab; upper surface very irregular	4	0
Sandstone, massive	8	0
Sandstone, shaly	18	0
Shale, gray, sandy	7	0
Sandstone, yellow, massive	5	6
Shale, gray, sandy	17	0
Sandstone, massive	3	0
Shale, drab	2	0
Sandstone, massive	14	0
Shale, drab to dark, sandy and concretionary	5	6
Shale, platy, gray and drab	11	0
Oolite		6
Sandstone, finely cross-bedded, poorly cemented	5	0
Oolite		10
Sandstone, massive	2	0
Shale, drab, sandy	3	10
Sandstone, massive	1	6
Shale, drab	3	3
Sandstone, massive	3	0
Shale, gray and drab	102	0
Sandstone, minutely cross-bedded		8
Shale, gray and drab	97	0
Oolitic sandstone, forming ledge; lower 4 inches conglomeratic and may well be considered basal member at Green River	1	4
Sandstone, yellow, poorly cemented	28	0
Shales, red and green, undoubtedly Wasatch.	1,306	10½

Location R, north side of Saddle Post Canyon, sec. 22, T. 11 S., R. 25 E.

	Ft.	in.
Shale, hard, rich, weathers papery (sample 76; 31 gallons)	2	11
Shale, rather soft, white on surface, platy (sample 76; 31 gallons)	1	7
Shale, hard, rich (sample 75; 35 gallons)		10
Shale, white, platy (sample 75; 35 gallons)		9
Shale, hard, rich (sample 75; 35 gallons)		9
Shale, lean to rich; weathers papery	1	6
Shale, lean; weathers white and platy	1	3
Shale, rich; weathers papery		6½
Shale, lean; weathers white and platy	2	4
Shale, hard, rich		10
Shale, lean	12	0
Shale, hard, rich		4
Shale, lean, platy	4	8
Sandstone, persistent, quartzitic (identical with 5-inch sandstone at location Q; see p. 183)		5
	30	8½

Sections in northeastern Utah—Continued.

Location S, sec. 24, T. 11 S., R. 25 E.

	Ft.	in.
Sandstone		8
Shale, lean, sandy	20	0
Shale, rich		3
Shale, lean	6	0
Shale, rich	1	6
Shale, lean to barren	6	6
Sandstone		5
Shale, lean	4	6
Shale, rich		8
Shale, lean	4	0
Shale, rich		10
Shale, lean, papery	1	6
Shale, rich	3	6
Shale, soft (sample 78; 48 gallons)		2
Shale, rich		4
Shale, soft	1	7
Shale, rich		8
Shale, lean	2	0
Shale, rich	1	0
Shale, rich, and papery shale	4	0
Shale, medium rich	3	0
Shale, rich, hard		2
Shale, lean	4	0
Shale, medium rich	9	0
Shale, lean	4	0
Sandstone, ferruginous		5
Shale, lean to barren	4	6
Shale, hard, rich		6
Shale, lean to barren	5	0
Sandstone, coarse, asphaltic (same as 22-inch asphaltic sandstone at location Q; see p. 183)	1	1
	91	9

Location T, on north side of Hells Hole Canyon, sec. 22, T. 10 S., R. 25 E.

	Ft.	in.
Shale, platy, sandy, lean to barren	15	0
Shale, mostly lean, with rich beds too thin to sample	11	0
Shale, thin, platy	1	11
Shale, hard, rich (sample 91; 29 gallons)	3	2
Shale, lean	2	1
Sandstone, persistent		5
Shale, lean, platy, containing one 6-inch bed of rich shale	6	5
Shale, hard, very rich	3	2
Shale, very sandy, lean		11
Shale, hard, rich (sample 90; 45 gallons)	4	8
Shale, hard	1	3
Shale, soft (sample 89; 17 gallons)	1	4
Shale, hard, rich	1	5
Shale, lean to barren	1	9
Shale, rich (A)		1
Shale, soft (B)		1½
Shale, rich (A)		3½
Shale, soft (B)		3½
Shale, rich (A)		½
Shale, soft (B) (sample 86, of whole bed, 37 gallons; sample 87, of parts of bed marked "A," 54 gallons; sample 88, of parts of bed marked "B," 25 gallons)		1
Shale, rich (A)		5
Shale, soft (B)		7
Sandstone (discarded)		1
Shale, soft (B)		6
Shale, rich (A)		1
Shale, soft (B)		2
Shale, rich (A)		½
Shale, soft (B)		5
Shale, rich (A)		1½
Shale, lean	1	8
Shale, hard, rich (sample 85; 22 gallons)	1	8
Shale, lean mostly, with rich layers too thin to sample	7	6
Shale, hard, rich (sample 84; 21 gallons)	7	8
Shale, hard, lean to rich, cliff forming	7	4
Sandstone, asphaltic		3
Sandstone, coarse		1½
Shale, hard	1	0
Sandstone		1
Shale, hard, rich (sample 83; 8 gallons)	2	11
Shale, hard, richest in upper 2 feet (sample 82; 20 gallons)	6	0
Sandstone, asphaltic, variable in thickness (same as 22-inch asphaltic sandstone at location Q, see p. 183)	1	4
Shale, hard, rich (sample 81; 24 gallons)	1	11
Sandstone		1
Shale, sandy, platy, lean to barren	28	0
Shale, rich		3
Shale, lean to barren, sandy	2	4
Shale, rich		2
Shale, lean to barren	2	6
Sandstone		1
Shale, gray, lean to barren	18	6
Shale, hard, rich		2
Shale, gray, lean to barren	2	10
Shale, alternating hard and soft layers	2	4
Shale, soft (sample 80; 33 gallons)	1	0
Shale, alternating hard and soft layers	1	3
Shale, lean	5	0
Shale, rich		1
Shale, papery, or sandy and platy, lean	34	0
Shale, rich		10
Shale, sandy, platy, lean to barren	37	0
Shale, rich		10
Shale, barren		6
Shale, hard, rich		1
Shale, platy, barren	5	0
Shale, hard, rich		2
Shale, for the most part gray and lean, but a few rich layers less than 1 inch thick	85	0
Shale, papery, lean	8	0
Shale, platy, lean	3	6
Shale, hard, rich		3
Shale, sandy, barren	3	0
Shale, hard, rich		2

Sections in northeastern Utah—Continued.

Location T, on north side of Hells Hole Canyon, sec. 22, T. 10 S., R. 25 E.—Continued.

	Ft.	in.
Shale, thin, platy, lean to barren	30	0
Oolite		5
Shale, papery, lean	3	8
Shale, hard, rich		1½
Shale, barren		6
Shale, hard, rich		2
Shale, thin, platy, barren	16	0
Oolite		4
Shale, thin, platy, barren	1	2
Sandstone		7
Shale, thin, platy, barren	16	0
Cherty layers, distorted, concretionary	1	0
Oolite, conglomerate at base	2	4
Shale, gray and drab, barren	2	4
Sandstone		8
Shale, gray and drab, barren	1	10
Sandstone, concretionary	3	6
Shale, gray and drab, barren	20	0
Sandstone, with oolitic bands	4	0
Oolite	3	9
Shale, gray and drab, barren	23	0
Oolite, top distorted and sandy	3	0
Sandstone, oolitic	5	0
Shale, gray	28	0
Sandstone, shaly	15	0
Sandstone, massive	4	0
Shale, barren, gray, sandy	18	6
Oolite	3	6
Shale, barren, gray sandy	10	0
Oolite	2	0
Sandstone	2	0
Shale, barren, gray, sandy	65	0
Oolite	1	0
Sandstone	3	0
Shale, gray, lean to barren	19	0
Oolite		6
Sandstone, twisted and deformed	1	10
Oolite	6	6
Shale, gray to drab, barren	19	0
Sandstone, massive, yellow	12	6
Shale, gray	5	0
Oolitic sandstone	4	0
Shale, sandy	13	0
Sandstone, massive, yellow, cross-bedded	10	6
Shales, gray and drab, barren	45	0
Sandstone, mostly yellow and massive, but with two somewhat shaly zones	41	0
Shale, sandy, barren	21	0
Shale, rich		6
Shale, gray and drab, barren	35	0
Sandstone and barren, sandy shale	37	0
Shale, largely masked, mostly drab, papery, with sandy zones; not sufficiently cemented to form ledges	95	0
Sandstone, coarse, yellow	1	10
Shale, lean to barren, papery	7	0
Sandstone, yellowish		6
Shale, soft, sandy (sample 79; 1 gallon)	4	1
Sandstone		3
Shale, masked, but for the most part a barren greenish shale	26	0
Sandstone, yellowish brown, poorly cemented	10	0
Shales, red and green (Wasatch).		
	1,047	5

The following stratigraphic sections were measured in southwestern Wyoming and show the general character of the Green River formation in the southern parts of the Green River and Southern Red Desert basins:

Sections of parts of Green River formation in southwestern Wyoming.

T. 14 N., R. 99 W.

	Ft.	in.
Sandstone, coarse grained, not massive	50	0
Sandstone, containing fossil shells		4
Sandstone, coarse grained, thin bedded	10	0
Covered, probably sandy shale	35	0
Sandstone, coarse	8	0
Covered, mostly shale	30	0
Shale, papery, drab, lean	5	0
Shale, thin, barren and sandstone	72	0
Shale, drab, thin, lean	3	0
Shale, thin, drab, barren	20	0
Shale, thin, lean	30	0
Sandstone, concretionary	1	0
Shale, thin, lean	14	0
Oolite and chert		0
Shale, thin bedded, lean	14	6
Shale, thin bedded; weathers blue; rich	2	0
Shale, gray, sandy (not included in sample)	1	7
Sandstone, yellow (not included in sample)		1
Shale, thin bedded; weathers blue; rich	3	0

(sample 92; 30 gallons).

Shale, yellow, sandy	28	0
Shale, papery, lean	40	0
Shale, drab, fissile	10	0
Sandstone, concretionary	1	0
Shale, drab, papery	13	0

Sections of parts of Green River formation in southwestern Wyoming—Continued.

T. 14 N., R. 99 W.—Continued.

	Ft.	in.
Oolite		6
Shale, drab, papery	10	0
Sandstone, oolitic		4
Shale, drab, fissile	12	6
Sandstone, micaceous	1	0
Sandstone, yellowish	3	0
Shale, drab, thin sandstone lenses	26	0
Sandstone, shaly, yellowish	1	0
Shale, drab, papery, barren	5	0
Sandstone, shaly, yellowish	1	6
Shale, greenish drab	37	0
Maroon clay shale (probably Wasatch).		
	489	10

T. 13 N., R. 108 W.

	Ft.	in.
Sandstone, ferruginous, containing fossil shells		6
Shale and sandstone	500±	
Shale, thin, brown	5±	
Shale, thin, brown (sample 100; 3 gallons)	5	0
Shale, thin, brown	2	6
Shale, hard, black, rich... (sample 99; 19 gallons).		½
Shale, brown, soft		5
Shale, hard, black, rich...		1
Shale, brown, soft		8
Shale, hard, black, rich...		2
Shale, brown, soft	1	8
Shale, hard, black, rich...		3
Shale, light brown, lean (sample 98; 3 gallons)	5	0
Interval	25	0
Shale, lean (?)	10±	
Shale, dark brown (sample 95; 13 gallons)	5	0
Shale, thin bedded, tough	10	6
Shale, thin bedded, tough (sample 96; 4 gallons)	5	4
Shale, thin bedded, tough	2	6
Shale, massive, light brown	2	6
Shale, massive, light brown (sample 97; 6 gallons)	4	10
Shale, lean.		
	586	11½

Sec. 27, T. 17 N., R. 106 W.

	Ft.	in.
Shale, drab	45	0
Sandstone, platy	16	0
Shale, lean	22	0
Sandstone, brown, platy	7	0
Shale, hard, not so rich	24	0
Shale, hard, thin, platy [a] (sample 118; 14 gallons)	5	6
Shale, hard, dark [a]	2	3
Shale, hard, dark, rich [a] (sample 117; 19 gallons)	8	1
Shale, weathers to thin plates; part of member will yield small amount of oil	120	0
Covered, mostly light-colored shale or clay	75	0
Clay, mostly gray, with some red	80	0
Clay, gray, yellow, green, and red, with beds of yellow sandstone. All beds very lenticular. A 40-foot bed of massive sandstone at one place splits and within 100 yards along its outer top is represented by variegated clay beds, with a few thin sandstones	75	0
	479	10

Secs. 17 and 19, T. 17 N., R. 106 W.

	Ft.	in.
Sandstone, massive, brown, coarse (Tower sandstone of Powell)	125	0
Sandstone, thin bedded	35	0
Shale, papery, gray	25	0
Sandstone, shaly, gray	32	0
Shale, sandy, lean	65	0
Shale, hard; contains fish remains (sample 120; 14 gallons)	5	0
Shale, lean	20	0
Shale, thin with lenses of very rich waxy shale	55	0
Shale, hard	15	0
Shale, hard (sample 119; 12 gallons)	5	0
Shale, hard, lean	12	0
Shale, gray, sandy	20	0
Shale, hard, rich	1	4
Shale, gray, sandy, thin sandstones, and a few 1 to 3 inch beds of rich shale	90	0
Shale, hard, thin, medium rich	1	6
Shale, barren	15	0
Shale, medium, with large gypsum crystals	1	6
Shale, thin, barren	80	0
Shale, medium, with gypsum crystals		8
Shale, gray, sandy	26	0
Shale, medium, with gypsum crystals	1	6
Shale, hard, rich		10
Sandstone, thin, gray	8	0
Shale, hard, rich		10
Shale, gray, sandy	17	0
Shale, hard, rich		2
Shale, thin, gray, sandy	9	2
Shale, hard, rich		0
Shale, sandy	118	0
Sandstone, gray	4	0
Shale, sandy, greenish	6	0

[a] Probably same zone as lower 22 feet 8 inches of section measured in secs. 17 and 19 of this township.

Sections of parts of Green River formation in southwestern Wyoming—Continued.

Secs. 17 and 19, T. 17 N., R. 106 W.—Continued.

	Ft.	in.
Sandstone, gray, thin bedded	1	0
Shale, sandy, green	27	0
Shale, sandy, thin bedded, gray	21	0
Sandstone and shale, green, in beds 2 feet thick; sandstone, concretionary	58	0
Shale, sandy, gray, slope	97	0
Sandstone, massive, cross-bedded, forming ledge and capping hill	5	0
Shale, forming slope	43	0
Sandstone, rather massive, forming ledge	10	0
Shale, soft, thin, platy, barren	30	0
Shale, medium hard, rather thin, very lean	4	11
Shale, medium hard (sample 116; 4 gallons)	4	10
Shale, sandy, lean to barren	70	0
Shale, medium hard, very lean	10	0
Shale, lean	4	6
Sandstone, brown, persistent		8
Shale, lean	3	6
Shale, hard to medium hard (sample 115; 9 gallons)	4	6
Shale, lean to barren	75±	
Shaly sandstone, barren	15	0
Shale, sandy, forming slope, lean	47	0
Shale, hard (sample 114, lower 4½ feet; 11 gallons)	5	6
Shale, hard (sample 113; 10 gallons)	5	3
Shale, hard	1	4
Sandstone (sample 112; 9 gallons)		3
Shale, fairly soft, thin-bedded (sample 112; 9 gallons)	2	9
Shale, hard (sample 112; 9 gallons)	1	0
Shale, hard, rich (sample 111; 19 gallons)	5	4
Shale, hard, rich (sample 110; 19 gallons)	6	3
Shale, soft		7
Shale, hard, rich (sample 109; 11 gallons)	2	5
Shale, soft (sample 109; 11 gallons)		6
Shale, hard, rich (sample 109; 11 gallons)	2	3
	1,360	10

Along Bitter Creek, T. 18 N., R. 107 W.

	Ft.	in.
Sandstone, massive, brown	135	0
Shale, lean to barren	3	0
Shale, hard	6	0
Sandstone, brown, massive	1	0
Shale, lean to rich	1	0
Sandstone, brown, massive	5	0
Shale, lean, papery	11	0
Sandstone		2
Shale, hard, rich		6
Sandstone		3
Shale, hard, dark (sample 128; 7 gallons)		8
Shale, brown, tough (sample 128; 7 gallons)		4
Shale, hard, rich, dark (sample 128; 7 gallons)	1	4
Sandstone		3
Shale, hard, rich	2	6
Shale, hard, rich (sample 127; 18 gallons)	6	3
Sandstone		6
Shale, hard, rich	6	2
Sandstone, hard, massive		6
Shale, hard, gray, sandy, lean to barren	13	0
Shale, soft, greenish, lean	15	0
Partly masked, barren gray shale and sandstone, with some lean papery shale	55	0
Sandstone, platy	2	0
Shale, lean, soft	2	6
Shale, greenish gray	21	6
Sandstone, thin bedded	11	0
Covered, mostly barren gray sandy shale, with a few ledges of gray shaly sandstone	128	0
Sandstone, platy	3	0
Shale, greenish	7	0
Covered, mostly barren gray sandy shale, with a few ledges of gray shaly sandstone	110	0
Shale; weathers papery	1	6
Sandstone		6
Shale; weathers papery	2	0
Shale, gray, sandy, with layers of shaly sandstone	21	0
Shale, greenish	20	0
Shale, gray, sandy, with layers of shaly sandstone	17	0
Shale, greenish, with brown sandstone lentils	20	0
Sandstone, brown, with some clay shale	35	0
Sandstone, thin, platy	4	0
Sandy shale and shaly sandstone, gray, barren	85	0
	755	5

White Mountain, sec. 36, T. 19 N., R. 106 W.

	Ft.	in.
Sandstone, brown, coarse (tower sandstone of Powell)	245	0
Shale, gray, sandy, and shaly sandstone, with three beds of rich shale each 3 inches thick in lower part	265	0
Shale (estimated yield, 12 to 15 gallons)	3	0
Shale, gray, sandy, and thin sandstone with two or three 1-inch beds of rich shale	37	0
Sandstone, gray, ripple marked	1	0
Shale, sandy, gray, and shaly sandstone	22	0
Sandstone, shaly, yellow	2	0
Shale, sandy, and clay, with a few thin sandstone beds; color predominantly white	133	0
Sandstone, green, shaly	33	0
Shale, gray, sandy, and thin sandstone	58	0
Shale, green, sandy, and green sandstone	17	0
Shale, greenish drab, sandy	35	0
Sandstone, chalky, cross-bedded, brown	2	0

Sections of parts of Green River formation in southwestern Wyoming—Continued.

White Mountain, sec. 36, T. 19 N., R. 106 W.—Continued.

	Ft.	in.
Shale, drab, sandy	95	0
Sandstone, ferruginous		4
Shale, sandy, gray-green, and shaly sandstone	75	0
Sandstone, shaly	2	0
Shale, papery, lean, with 2-inch beds of rich shale and some thin beds of sandstone	87	0
Sandstone, with clay balls		6
Shale, papery, lean	26	0
Shale, sandy, gray	24	0
Sandstone, shaly, gray, fossiliferous	2	0
Shale, carbonaceous	8	0
Clay, sandy, gray	40	0
Sandstone, coarse, gray, possibly base of Green River formation	1	0
Clay, somewhat sandy, gray	55	0
Shale, clay, variegated, red at top	33	0
Sandstone, yellowish green, friable	30	0
	1,331	10

Fossil Butte.

	Ft.	in.
Sandstone, shaly	95	0
Sandstone, coarse, brown		3
Shale, hard, rich, dark; weathers blue (sample 131; 50 gallons)	2	0
Sandstone, shaly	7	0
Shale, hard, rich; weathers blue	1	0
Alternating bands of coarse sandstone and shale	8	0
Sandstone, cherty		10
Shale, lean, chalky, thin bedded	15	0
Sandstone, reddish brown		8
Shale, lean, chalky, thin bedded	2	6
Sandstone, massive	8	6
Chalk		3
Sandstone, massive, yellow	3	2
Shale		10
Sandstone, gray (discarded)		5
Shale, hard, light brown	1	7
Sandstone, light brown (discarded)		4
Shale, hard, brown, rich; weathers blue	1	1
Sandstone, yellow		¼
Shale, hard, brown, rich; weathers blue		11

(sample 130; 10 gallons).

	Ft.	in.
Shale, white, chalky		10
Shale, hard, brown		6
Shale, white, chalky; contains abundant fish remains	1	2
Shale, lean, thin bedded	18	0
Sandstone, drab	10	0
Shale, sandy	5	0
Sandstone, coarse	65	0
	250	1¼

(sample 129; 8 gallons).

STRUCTURE.

Northwestern Colorado and northeastern Utah.—The Uinta Basin is a broad, shallow syncline whose central portion is occupied by the Green River and younger formations. The Green River beds are only slightly tilted at most places around the margin of the basin, but the older formations dip at much greater angles only a few miles beyond the limits of the Green River formation. The Douglas anticline, which extends southward from Rangely, brings up the Mesaverde and Wasatch formations and perhaps entirely separates the main Colorado area of the Green River formation from the much larger area in northeastern Utah, and it is almost certain that the areas of oil-yielding shale are completely separated. Although the Green River formation dips sharply (maximum observed dip 28°) toward the interior of the basin at its margin along the north and east sides of the Colorado area, the dip decreases very rapidly,

so that a few miles back of the margin the shale is horizontal or dips only slightly.

Small faults were observed at a few places, although it is probable that the broad movement which produced the great synclinal structure gave rise to fracture zones or cracks and faults at many other places. The great veins of gilsonite in the vicinity of Dragon, Utah, are cracks filled with the asphaltic material. West of the Petrolite Hills, in the eastern part of the area studied, a fracture zone cutting the Green River formation is filled with a very light yellowish-brown hydrocarbon (specific gravity 1.06) which does not answer the description of any of the ordinary asphaltites. The deposit may not be sufficiently extensive to be of economic importance, but it is of considerable scientific interest. The fracture zone in which the material is found is 2 or 3 feet wide and has been traced for several miles in a

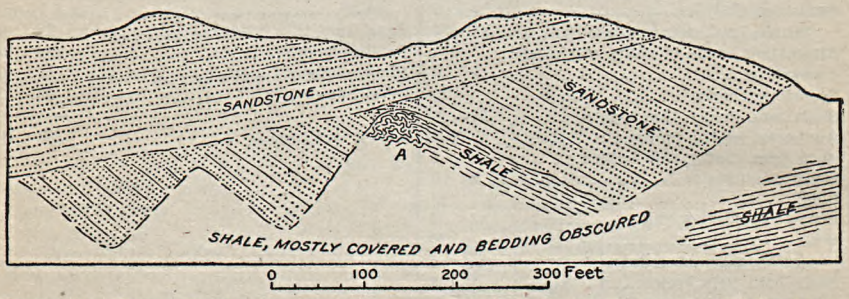


FIGURE 14.—Diagram showing structure in the Green River formation near the mouth of Yellow Creek, Colo.

general northwest-southeast direction. Several small prospects have been opened along it.

On Yellow Creek, sec. 15, T. 2 N., R. 99 W., a heavy brown sandstone rests on a very irregular surface, and the shale beneath (A, fig. 14) is very much distorted, exhibiting in places very definitely overturned folds, as well as faults on a small scale. It is not at all impossible that the brown sandstone marks the base of a formation which should be separated from that below, but in this paper it is included in the upper part of the Green River formation. The massive sandstone appears to fill channels, yet the distorted condition of the shale beneath would suggest that the shale was still in a plastic condition after the deposition of part of the sand and that the sand settled unevenly, giving rise to the many peculiar forms which are exhibited in the shale beds beneath. After this settling the deposition of sand was continued over the edges of the portions of the sand which had been displaced. This appears to represent a change in conditions of deposition which may have more than local importance.

Southwestern Wyoming.—That part of southwestern Wyoming (see Pl. X) lying between the Uinta Mountains on the south and the Wind River Mountains on the north is in a broad structural basin which is separated into several smaller basins by north-south uplifts. Oil-yielding shale is present in three distinct areas; the central area, to which the name Green River basin is applied, is by far the largest. The Rock Springs uplift, on the east, described by Schultz,[1] and related features near the Colorado-Wyoming State line, to the southeast, separate the main area from the much smaller Southern Red Desert Basin, only the rim of which is shown on Plate XIX (in pocket). On the west the Green River basin is separated from the area of the Green River formation in the vicinity of Fossil, described by Veatch [2] as the Fossil syncline, by an anticlinal fold which the same author called the Meridian anticline.

Beds of the Green River formation are only slightly tilted in any part of the area shown on Plate XIX. Along the western rim of the Southern Red Desert Basin the oil shale at its outcrop dips as much as 11° NE., but it flattens rapidly toward the center of the basin. Along the east and west sides of the main Green River basin the oil-yielding shale shows dips not exceeding 3° or 4°, but in some places along the north flanks of the Uinta Mountains the beds of the Green River formation are tilted at greater angles. The oil shale of the Fossil syncline is practically horizontal at every point examined.

Faults in the Green River shale were noted in only one area, but they may be present at many other places within the area here described. West of Green River, near the center of T. 15 N., R. 108 W., there is an area perhaps half a mile wide and extending an unknown distance to the west, where the rocks are crumpled and cut by east-west trending faults. On both sides of this disturbed zone the strata are apparently unaffected.

The channel sandstone of Lee,[3] which is the Tower sandstone of Powell,[4] forms vertical cliffs in the vicinity of Green River, Wyo., where it rests on an irregular surface of shale and is itself very much distorted, whereas the shale beneath is not deformed.

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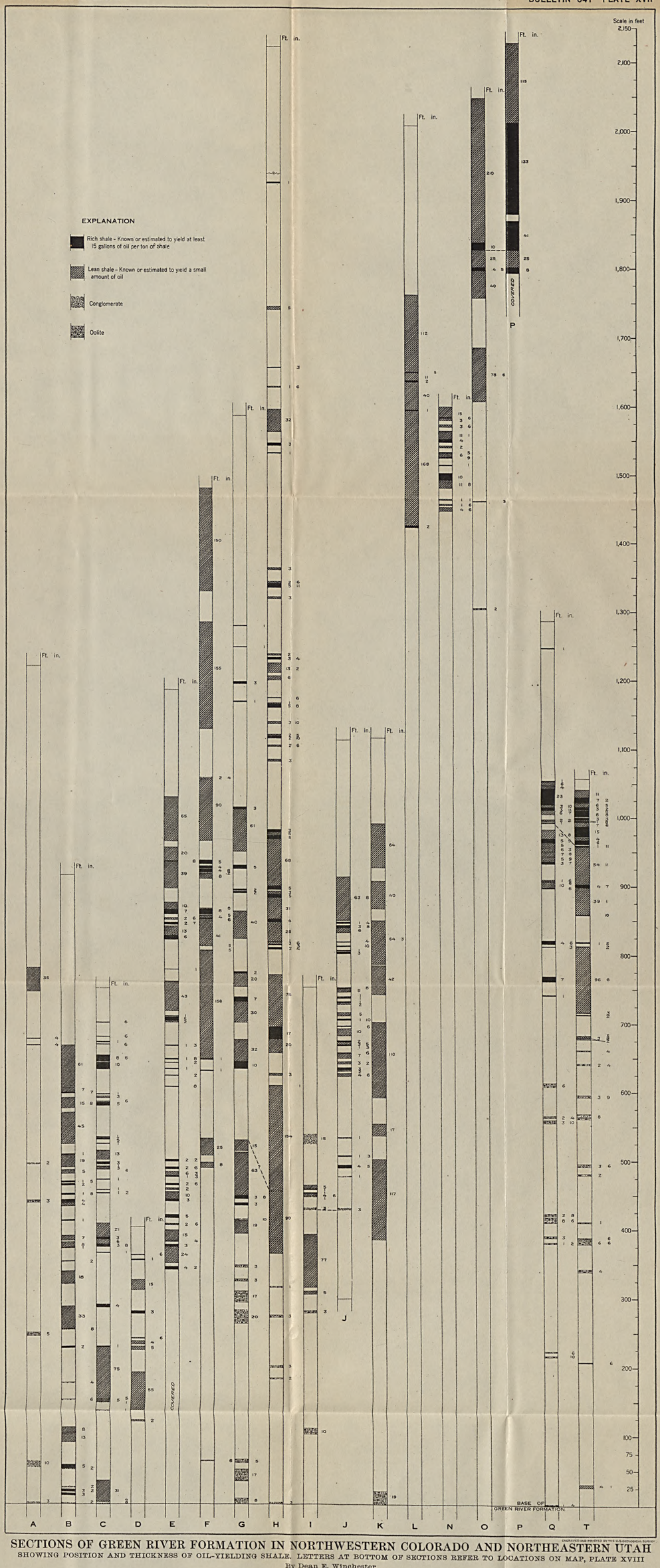

SECTIONS OF GREEN RIVER FORMATION IN NORTHWESTERN COLORADO AND NORTHEASTERN UTAH

SHOWING POSITION AND THICKNESS OF OIL-YIELDING SHALE. LETTERS AT BOTTOM OF SECTIONS REFER TO LOCATIONS ON MAP, PLATE XVIII

By Dean E. Winchester

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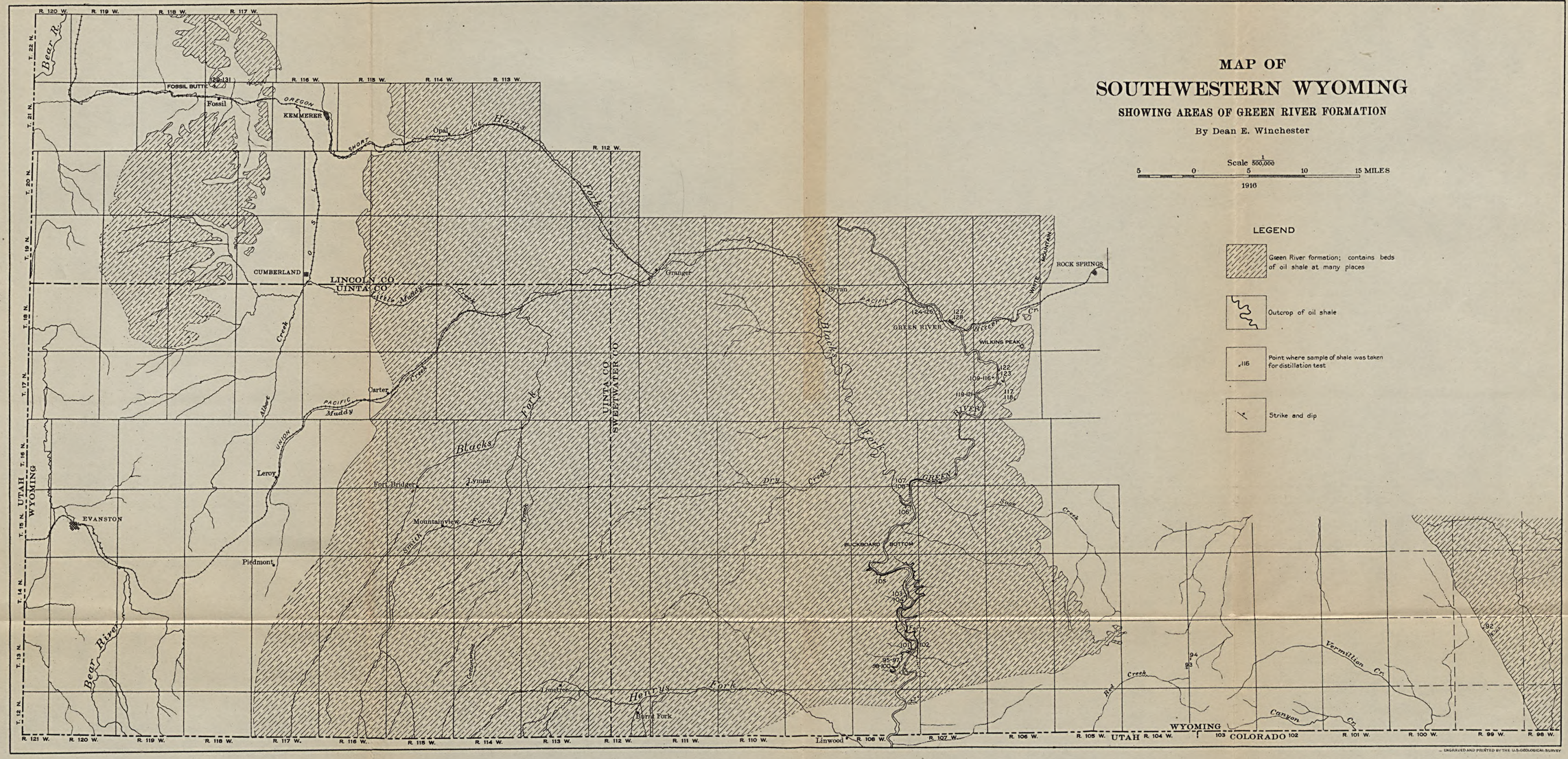

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MAP OF NORTHWESTERN COLORADO AND NORTHEASTERN UTAH

SHOWING AREAS OF GREEN RIVER FORMATION

By Dean E. Winchester

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