DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 581—A

OIL SHALE OF NORTHWESTERN COLORADO AND NORTHEASTERN UTAH

BY

E. G. WOODRUFF

AND

DAVID T. DAY

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1913, PART II—A

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OIL SHALE OF NORTHWESTERN COLORADO AND NORTHEASTERN UTAH.

By E. G. Woodruff and David T. Day.

INTRODUCTION.

It has been known for many years that highly bituminous shale, or oil shale, occurs in the Green River formation of the Uinta Basin in Colorado and Utah. Eldridge,[1] who studied the gilsonite veins in this region in 1901, incidentally mentions the shale. He states that the Green River formation includes "shales and limestones, bituminous, locally in a degree to be of economic value." Since the publication of that paper reports have been current from time to time that this shale is rich in petroleum, and that it compares favorably with the Scotch oil shale which has been successfully utilized in the commercial manufacture of petroleum products for half a century.

In order to determine the geographic distribution and thickness of the shale E. G. Woodruff, assisted by W. P. Woodring, carried on in the summer of 1913 a reconnaissance survey of a part of the area occupied by the Green River formation in Utah and Colorado and in collaboration with D. T. Day made field tests to determine the amount of oil and other distillation products that can be obtained from the shale. Later Mr. Day made laboratory tests of some of the same shale and also examined the oil obtained in the field in order to determine its quality and to see if by better methods of distillation its quality could be improved.

The results of the season's work, though not of such a character as to demonstrate the feasibility of immediate utilization of the shale in the production of petroleum, seem to indicate that there is here a large reserve supply of oil, which sooner or later will be used to supplement the product of the well-known oil fields.

The results of the tests and of the areal distribution and character of the shale are here briefly stated in the hope that technologists may be interested in the investigation and may actually prove on the ground whether or not the shale can be utilized at the present time.

[1] Eldridge, G. H., The asphalt and bituminous rock deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 1, pp. 219-452, 1901.

THE SHALE.

OCCURRENCE AND CHARACTER.

The areal distribution of the shale has been determined in a general way only. In Utah it extends northward from its line of outcrop, shown in Plate I, toward the interior of the Uinta Basin, but its limits in that direction can only be conjectured because its northward extension is concealed beneath more recently deposited beds, which overlap it unconformably. It is probable, however, that bituminous shale underlies nearly all the deeper parts of the Uinta Basin in this State. In Colorado only the southern edge of the area was examined, but previous geologic work in adjacent areas to the east and north, where the base of the Green River formation has been mapped, indicates that the area containing shale is very similar in shape to that of the outcrop of the Green River formation (see Pl. I, p. 18), though considerably smaller. It is believed that in Utah the greatest depth of the shale below the surface in the center of the basin exceeds 2,000 feet but that in Colorado it is much less.

Bituminous shale occurs in lenticular beds ranging from a fraction of an inch to 80 feet in thickness. A continuous exposure of half a mile or so generally reveals only a moderate amount of variability, but the study of a township shows a great range in thickness and lack of continuity in the lenses. At some places the shale beds are thick and have a fairly uniform content of bitumen throughout, whereas at others the beds are split into many thin members some of which are rich in bitumen while others contain only moderate quantities.

The bituminous shale does not split or break easily but separates readily from the associated beds. This ease of separation from the adjacent material is an important factor in the development of a shale-oil industry, as the shale can thus be readily separated in mining from the other material carrying little or no bitumen.

PHYSICAL PROPERTIES.

The shale is light to dark brown, thin but slightly irregularly bedded, has a velvety luster, and gives when scratched a light-brown streak. When examined under a hand lens the streak is seen to have a vitreous luster, which appears to be produced by a thick fatty substance. In many specimens rich bituminous layers alternate with leaner streaks. These layers are not cleavable one from another, yet one merges sharply into the other; consequently it is difficult to separate the lean and fat shale in laboratory practice and impracticable in commercial processes. The shale is very tough, being split along the bedding planes with difficulty, and it strongly resists breaking across the stratification. When broken it exhibits splintery edges. From hand specimens it is evident that the shale contains considerable bitumen and when hit with a hammer it gives off a petroleum odor. A sliver inserted in a flame burns with a sooty smoke and gives an odor of burning petroleum. When blocks of the shale are ignited in a pile the pieces soften under the effect of the heat and become about as plastic as hot asphalt paving. Complete combustion leaves only a gray residue, composed mostly of clay, lime, and sand.

The major bedding and a large part of the minor bedding are regular, but in most of the rich shale there is an irregularity of lamination which gives to it a peculiar curly structure like the curling of oak wood about a knot. This structure is so well shown in weathered specimens, as the result of the differential alteration of the fat and lean laminæ, that such material was called in the field "curly shale." The "curly shale" was found to be richer in bitumen than the shale composed of regular and even laminæ. Chemical and microscopic examinations of the shale reveal a most intimate mixture of calcite and small quantities of quartz in fine round grains and clay, embedded in a mass of macerated vegetable débris consisting in part of cells, spores, wood, and pollen grains. Some specimens may show the flowage of oil residue, but this has not been conclusively demonstrated.

The specific gravity of the shale is shown in the following table from tests made by W. T. Schaller:

Specific gravity of bituminous shale.

Kimball Creek	1.63
Do	1.62
Do	1.66
Conn Creek	1.52
Average	1.60

When fresh bituminous shale is exposed to the air it changes to a light brown and finally, on continued exposure, to gray. Weathered samples of the best shale were found to be light gray, whereas less rich ones are darker in color. On account of this change of color from weathering many persons have been misled, thinking that the darker color indicated greater richness than the lighter color. Weathering does not seem to have affected the shale deeply, though there are some indications that the shale under cover is richer than that along the outcrop.

FIELD TESTS.

Field tests were made in a portable still designed by Mr. Day and operations were at first carried on under his immediate supervision. Mr. Day remained in the field until the apparatus was thoroughly tested and then the work was carried on by Mr. Woodruff at various places accessible to the railroad where an abundant supply of the best shale could be procured. The basic principle of the operation was to heat the shale, thus vaporizing the volatile hydrocarbons and destructively distilling the other forms of organic matter present in the shale.

The distillation products were conducted through a pipe to a condensing coil, where the heavier products were liquefied and conducted into receivers and the gases permitted to escape.

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, 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. The liquid products were sealed in cans and shipped to the Washington laboratory. The results of the field tests are as follows:

Results of field distillation of shale.

No. of test.	Locality.	Thickness of shale sampled.	Amount of shale used.	Amount of oil obtained.	Amount of oil to the short ton of shale.	Section on p. —
		Ft. in.	*Pounds.*	*Gallons.*	*Gallons.*	
1	Conn Creek	1 4	100	3.1	61.2	20
2	Kimball Creek	6 0	150	2.4	31.6	15
3	Kimball Creek (second test)	6 0	156	2	26.2	15
4	Parachute Creek	5 10	150	1.5	20.0	12
5	4A ranch	5 10	150	.78	10.4	14
6	Temple station	4 0	120	2.7	45.2	17
7	Ute station	2 0	120	.96	16.0	17
8	White River, subsurface sample	3 6	150	2.5	33.3	18
9	White River, sample taken near surface	3 6	135	2.4	35.5	18
10	Ninemile Creek	6	105	2.1	39.0	19
11	Hill Creek	9	135	1.3	16.0	19

From the table given above it will be seen that the amount of oil obtained in the various tests ranged from 10.4 gallons to the ton in test No. 5 to 61.2 gallons in test No. 1, the average for the entire series being 30.4 gallons. The commercial utilization of the shale as a source of petroleum depends upon the quality of the oil produced and the amount and accessibility of the shale. The quality of the oil obtained in the field tests was determined by Mr. Day in the Survey laboratory at Washington and the results of his examinations are given later, together with a brief discussion of ways and means of improving results. With regard to the amount of shale, the evidence at hand is not so conclusive. The thickness of the bed of shale at the point sampled is given in the table. Some of the beds that were tested are too thin to be profitably mined under present conditions, but they were sampled because of the richness of the shale which they contained. If the beds less than 3 feet in thickness are disregarded the yield will run from 10.4 gallons in sample No. 5 to 35.5 gallons in sample No. 9, the average being 22.5 gallons to the ton of shale. As this average will compare favorably with the yield of the Scotch oil shale, it seems probable that the shale of Utah and Colorado may at the lowest estimate equal in value that of the well-known shale of Scotland from which petroleum has been successfully manufactured for a long time. However, the full extent of the geographic distribution of the shale and its petroleum content have not been adequately determined and much additional field work must be done before these facts can be fully and satisfactorily known.

LABORATORY TESTS.

GENERAL CHECKING TESTS.

Method of the work.—As a check on the field work and also for the purpose of making tests which required special apparatus, samples of shale were distilled under the supervision of Mr. Day. The laboratory tests included distilling the shale in a regular distilling flask, using 100 grams for a charge. The flasks were heated electrically in the usual way and it was found possible to continue the heating until the glass melted. It was found also that when this stage had been reached practically all the volatile matter had been distilled from the shale, leaving a crumbling dry coke. The gases given off were collected and also the ammonia water. The percentage of ammonia was determined in the general chemical laboratory. Analyses of the gases are appended.

Care was taken in condensing the vapor from the distillation to use ice water in the condenser and this is probably the reason why slightly larger yields were obtained than in the field tests.

In selecting material for distillation the entire sample was picked over for average specimens, a large number of these were crushed down and thoroughly mixed, and the sample for examination was taken from this mixture.

Test of shale from "asphalt mine," Conn Creek, Colo., in sec. 1, T. 7 S., R. 98 W. sixth principal meridian.—A sample containing 100 grams of the shale from Conn Creek was heated for a period of about 6 hours. As soon as the shale was sufficiently hot to give off moisture the evolution of gas began. This evolution became more rapid and an especially large volume of gas was given off during the last period of the distillation. The gas was collected over water in half-gallon bottles and sealed for analysis. The bottles were numbered in order that the gas from each stage of the process could be examined separately.

The following yield of products was obtained from the distillation: Crude oil, 24.5 cubic centimeters; fixed gas, 10 liters; ammonia, 0.13 gram, equivalent to 1.02 grams of ammonium sulphate, or 22.5 pounds of ammonium sulphate to the ton of shale; specific gravity of oil, 0.90. The yield of oil to the ton of shale was 68 gallons.

Analyses of gases.—Examination of the gases from two of the distillations gave the following results, the ordinary Orsatt apparatus being used:

Analyses of gases collected in two shale distillations.

Distillation No. 2.

	Percentage composition.					
	Carbon dioxide.	Oxygen.	Carbon monoxide.	Unsaturated hydrocarbons.	Other hydrocarbons and nitrogen.	Total.
Bottle No. 1	12.70	1.56	1.56	11.10	73.08	100.00
Bottle No. 2	5.20	1.50	7.50	9.50	76.30	100.00
Bottle No. 3	3.20	2.00	6.00	10.00	78.80	100.00
Bottle No. 4	4.00	1.00	1.60	12.40	81.00	100.00
Bottle No. 5	12.40	.60	9.60	6.40	71.00	100.00

Distillation No. 3.

	Carbon dioxide.	Oxygen.	Carbon monoxide.	Unsaturated hydrocarbons.	Other hydrocarbons and nitrogen.	Total.
Bottle No. 1	19.0	0.5	0.3	0.3	79.9	100.00
Bottle No. 2	5.1	1.8	3.1	4.0	86.0	100.00
Bottle No. 3	2.0	None.	1.1	4.0	92.9	100.00

On repeating the distillation there was practically no change in yield or character of products. On account of the evolution of carbon dioxide in the latter part of the process, the shale itself was examined and found to be a mixture of true clay shale and a large percentage of calcite. It is evident, therefore, that much of the gas evolved last came from the dissociation of the calcium carbonate. At the highest temperatures some of this carbon dioxide was reduced by the coke to carbon monoxide.

RESULTS OF LEACHING WITH ETHER AND BENZOL.

Much of the bituminous material in the shale occurs in the form of liquid oil and semisolid and solid asphalt, as shown by the extraction with ether and with benzol. By extraction with ether oil to the extent of 6.2 per cent by weight of the shale was obtained. By reextracting with benzol an additional 6 per cent was obtained, showing that 12.2 per cent of the total weight of the shale existed in the form of oil and asphalt. Thus at least half of the oil and asphalt obtained existed in the shale and is not formed by destructive distillation. When this oil is redistilled it undergoes further destructive distillation as well as fractionation, yielding oils having the usual gradations in gravity.

The odor of the oils distilled from the shale suggested phenol so strongly that some finely divided shale was boiled with 10 per cent solution of caustic soda, and the mixture, after acidifying, was shaken up with ether. By this means about 1 per cent of the total oil was found to consist of substances of the phenol class.

Qualitative tests showed the presence of pyridine compounds easily extracted from shale oil by dilute acids.

Experiments show that the bitumen existing in the shale is only very slightly soluble in methyl alcohol, but after boiling the finely divided shale with dilute hydrochloric or sulphuric acid, it was found that a much greater proportion of the shale was soluble in methyl alcohol, a fact which was confirmed by repetition.

EXAMINATION OF THE SHALE OILS DISTILLED IN THE FIELD.

For purpose of comparison the oils obtained by the field tests were distilled in Engler's distilling bulbs exactly according to the standard method of comparing crude petroleums, with the following results:

Results of distillation by standard method of the oils obtained in the field tests.

Serial No.	Location.	Physical properties.		
		Gravity at 60° F.		Color.
		Specific gravity.	Degrees Baumé.	
1	Kimball Creek	0.9302	20.5	Dark brown.
		a.8950	26.5	Dark red.
2	Parachute Creek	.9271	21	Dark brown.
		a.8805	29	Dark red.
3	Conn Creek, No. 1	.9103	24	Dark brown.
		a.8695	31	Red.
4	Conn Creek, No. 2	.9550	17	Dark brown.
		a.9060	24.5	Dark red.
5	4A ranch	.9369	19.5	Dark brown.
		(a)	....	Red.
6	Tunnel on Whisky Creek	.9537	16.8	Dark brown.
7	Tank at tunnel on Whisky Creek	.9550	17	Blackish brown.
8	Shale from Whisky Creek	.9550	16.75	Brownish black.
		(a)	....	Red.

a After treatment with sulphuric acid.

Results of distillation by standard method of the oils obtained in the field tests—Contd.

Serial No.	Location.	Distillation by Engler's method, by volume.							Unsaturated hydrocarbons (per cent).		Paraffin (per cent).	Asphalt (per cent).
		Begins to boil.	To 150° C.		150°-300° C.		Residuum.		Crude.	150°-300° C.		
		°*C.*	*C. c.*	*Sp. gr.*	*C. c.*	*Sp. gr.*	*C. c.*	*Sp. gr.*				
1	Kimball Creek	70	5	0.8020	54	0.8874	41.5	0.9649	66.8	64		2.210
		60	6	.8700	48	.8708	44.0	.9250		50	1.50	
2	Parachute Creek	75	2		48	.8646	50.5	.9437	91.6	45		1.907
		80	5	.8020	44	.8508		.9100		55	4.60	
3	Conn Creek, No. 1	70	4	.7745	42	.8519	53.4	.9085	75.6	44		.745
		80	2		38	.8373		.8928			3.13	
4	Conn Creek, No. 2	70	7	.8205	53	.8889			72.4	57		9.654
		70	10		55	.8585						
5	4A ranch	70	5	.7995	51	.8804	44.9	.9605	71.2	56		4.610
		70	6	.8355	38	.8783						
6	Tunnel on Whisky Creek.	220			35	.9116	65.9	.9550	69.6			None.
7	Tank at tunnel on Whisky Creek.	220			33	.9125			36.0			
8	Shale from Whisky Creek.	70	5	.8330	45	.8935			76.8	51		
		70	6	.8355	44	.8813					6.00	

HYDROGENATION OF SHALE OILS.

The shale oils obtained in Scotland and elsewhere and those obtained in the present series of distillations are characterized by a large proportion of unsaturated hydrocarbons, involving a considerable loss when these oils are refined. In refining them it is not necessary to remove all these unsaturated hydrocarbons but only those which prevent the manufacture of comparatively colorless and odorless oils by the usual refining process. The proportion of these compounds differs greatly in shales from different parts of the world.

In the distillation of the shale under consideration it is evident that when the process is carried on at the lowest possible temperature the quality of the oil obtained is considerably better.

The success which has lately attended the addition of hydrogen to unsaturated oils, by passing the vapors of the oils and hydrogen together through a porous substance acting as a catalyzer, has been sufficient to justify the treatment of these oils in the same way.

Accordingly a sample of 4.49 kilograms of shale from Temple station, Utah, was distilled under a pressure of 70 to 80 pounds, in an atmosphere of hydrogen. The still contained a coil of tubes filled with a catalyzer consisting of finely divided nickel with a small proportion of palladium (10 ounces of palladium to the ton of nickel). The catalyzer remained at the same temperature as the still. The vapor of the oil and the hydrogen passed together through the catalyzer before leaving the still. The distillation proceeded according to the following table.

Distillation of shale from Temple station, Utah, adding hydrogen under pressure.

[Charge, 4,490 grams in pressure still; continuous coil containing hydrogen with palladiumized nickel as a catalyzer. Residue, 2,850 grams of coke.]

Cut.	Amount of oil obtained (c. c.).	Gravity (°B.).	Temperature (°F.).	Pressure (pounds)
First	29	35.2	750-800	80
Second	20	33.2	750-800	80
Third	60	36.1	750-800	80
Fourth	63	38.1	750-800	80
Fifth	77	39.7	750-800	70
Sixth	44	35.1	750-800	70
Seventh	49	33.5	750-800	70
	342	[a] 36.0		
Eighth	50	25.9	750	70
Ninth	137	28.7	750-850	None.
Tenth	175	26.7	800-925	None.
Eleventh	180	24.4	900-1,000	None.

[a] Average.

First seven cuts steam stilled.

[Charge, 320 cubic centimeters.]

Cut.	Amount of oil obtained (c. c.).	Gravity (°B.).
First	25	63.2
Second	27.5	55.7
Third	20.5	50.0
Residue	165	26.1

These shale oils under ordinary redistillation yield oils ranging from 17° to 24° Baumé, whereas in the hydrogen distillation under pressure they ranged from 24.4° to 39.7° Baumé.

Further, when the first seven cuts were redistilled with steam the results showed a large yield of naphtha suitable for all purposes for which gasoline is used. The steam-stilled distillate, when treated with dilute caustic soda, had a marked odor of pyridine, which was easily removed with dilute sulphuric acid. The steam-stilled material required no treatment with acid to render it comparable with the other market grades of naphtha or gasoline. A similar distillation of shale from Parachute Creek, Colo., gave corresponding results, as shown in the table below, but was not completed on account of the accidental leakage of the still.

Distillation of shale from Parachute Creek, Colo., adding hydrogen under pressure.

[Charge, 4,200 grams in pressure still; continuous coil containing hydrogen with charcoal as a catalyzer. Pressure was also carried on condenser.]

Cut.	Volume of oil (c. c.).	Gravity (° B.).	Temperature (° F.).	Pressure (pounds).
First	115	35.4	750	70
Second	125	28.6	750	70
Third	20	25.0	750-850	70-30
Fourth	70	25.3	800	None.
Fifth	45	23.2	800-1,000	None.

EXTENT OF THE FIELD.

As shown on Plate I (p. 18) bituminous shale extends westward from Rifle, Colo., for a distance of 50 miles and in Utah from the east line of the State for a distance of 75 miles. In the two States there is a total direct east-west distance between extremities of outcrop of 125 miles, but owing to the sinuosities the total line of outcrop is probably twice as great. The extent of shale back of the outcrop has not been determined because neither the nature of the work nor the time and facilities available for it permitted such determination. However, the limits of the Green River formation, which contains the shale, are shown on the map (Pl. I). In Colorado the shale-bearing area is much less extensive than the formation but probably includes as much as 20 townships, whereas in Utah a much greater area contains the shale though most of it is too thin and covered too deeply to be worthy of economic consideration. In considering the areal extent of the shale it should be noted that the Colorado area is probably encircled by a belt of the shale outcrop, whereas in Utah the outcrop of the shale is along the southern side only, the northern being buried beneath younger overlapping formations. In this State shale is known to occur in Strawberry Valley west of Indian Creek (see Pl. I), but probably it is too thin to be considered economically.

SURFACE FEATURES AND CLIMATE.

Westward from Rifle, Colo., for 170 miles, to the vicinity of Colton, Utah, extend the high, steep, and locally precipitous Book Cliffs and Roan Cliffs, which rise 1,000 to 3,000 feet from a rather uneven lowland on the south to the high plateaus on the north. The cliffs do not form a continuous wall but are cut by many streams into a most intricate system of narrow steep-sided valleys between narrow spurs with precipitous sides. These cliffs are so high and so steep that an ascent has been found for a railroad at only one place and by a most tortuous narrow-gage route. Wagon roads cross the cliffs at a few favored spots, and difficult foot trails at fairly short intervals. From the crest of the cliffs a plateau slopes gently northward toward the interior of the Uinta Basin, through which flow White, Green, and Duchesne rivers. The surface of the plateau is cut into a most intricate system of badlands by branches of the streams which rise near the crest of the cliffs and flow northward to the rivers. The bituminous shale underlies the plateau and outcrops along its southern edge.

The region is semiarid—in fact, it is sometimes called a desert. Springs and brooks are common north of the crest of the cliffs, but generally the flow is so small that the water is lost by evaporation or seepage before it has gone far. A few perennial streams have a small flow of water, which is generally so alkaline, except near the source, that it is unsuited for the use of either man or animal. The vegetation consists of pines, cedars, and aspen in the higher parts of the plateau and of sagebrush and an extremely scanty growth of grass over the greater part of the area.

GEOLOGY.

The geology of the region was studied by Mr. Woodruff only in a general way at a few places along the southern exposures of the bituminous shale and to some extent back of the outcrop in Utah. These examinations, together with reports of previous workers in the field, furnish the data upon which the description of the geology is based.[1] Good exposures of the strata and the distinctive lithology of the rocks render geologic study simple and the results certain. Only general stratigraphic relations will be considered, except in so far as the data relate to the Green River formation, which will be described in detail because that formation contains the bituminous shale to which this report relates.

STRATIGRAPHY.

FORMATIONS PRESENT.

In western Colorado and eastern Utah the igneous basement is covered by a series of Paleozoic, Mesozoic, and Cenozoic formations many thousand feet thick. Among the last to be deposited were the Tertiary rocks, which in part are classified as follows:

Stratigraphic relations of the Green River formation to other Eocene formations in northwestern Colorado and northeastern Utah.

Formation.	Member.	Description.	Thickness.
Bridger formation.		Sandstone, very sandy shale, clay shale, and a few conglomerate beds; prevailing colors pink, brown, and gray. The Bridger is composed of loosely cemented rocks which weather into badland forms. Very irregular bedding is prevalent. Distinguished from the formation above by the slightly greater percentage of shale and by the fossils.	*Feet.* 600-1,000
Green River formation.	Upper.	Sandstone, very sandy shale, and some clay shale; prevailing colors brown and gray. The sandstone occurs in thick beds and locally contains fossil leaves. Generally even bedded, though not markedly so in central Utah.	500 (Estimated.)
	Middle.	Shale, thin bedded, some of it bituminous; thin beds of calcareous sandstone; prevailing colors, brown, gray, or faint green. This member is remarkable for its uniform thin bedding and for the large amount of bituminous matter which some of the beds contain. (Detailed sections are presented on pp. 13-20.)	100-700
	Lower.	Sandstone, shale, and oolite. The sandstone occurs in beds 1 to 15 feet thick. The shale is sandy, locally calcareous or bituminous, and very even bedded; prevailing colors brown, gray, or faint green. (A detailed section is presented on pp. 14-15.)	1,000-1,425
Wasatch formation.		Shale, generally very sandy, and sandstone. Colors variegated, red, maroon, pink, yellow, brown, and gray. Very irregularly deposited.	1,000-4,000

[1] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, 1910; Geology of the Rangely oil district, Colo.: U. S. Geol. Survey Bull. 350, 1908. Peale, A. C., Geological report on the Grand River district: U. S. Geol. and Geog. Survey Terr., Tenth Ann. Rept., 1878. Eldridge, G. H., Asphalt and bituminous rock deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 1, 1901. Richardson, G. B., Reconnaissance of the Book Cliffs coal field between Grand River, Colo., and Sunnyside, Utah: U. S. Geol. Survey Bull. 371, 1909. Woodruff, E. G., Geology and petroleum resources of the De Beque oil field, Colo.: U. S. Geol. Survey Bull. 531c, pp. 54-68, 1913.

GREEN RIVER FORMATION.

As the study of the oil shale involved the Green River formation only, the other formations were not given much attention. Consideration was given not only to the composition of the formation, but also to the character of the country and to the accessibility of the outcrops. Gale[1] has aptly said: "The valleys and lowland ridges commonly formed in the Wasatch clays are generally bordered by escarpment ridges of more resistant beds that overlie them. This escarpment-forming group of strata is known as the Green River formation." The cliff-forming feature of the Green River is the characteristic which first attracts attention to the formation, especially along the southern margin of the Colorado-Utah area. Closer inspection, however, reveals the even and generally thin bedding of the shale, the bitumen in some of the shale, and the calcareous character of the sandstone and oolite. Generally the oolite is composed of spherules less than one-eighth inch in diameter, but not uncommonly the rock is a pisolite whose spherules are as much as three-fourths inch in diameter. Ripple-marked sandstone beds occur in the lower and middle parts of the formation. Fish scales are common, and even fish remains occur at many places. Excellently preserved insects were obtained at one place and some imperfect specimens at another place. Some fossil turtles were also found.

Work was concentrated on that part of the section carrying the oil shale, and several sections were studied and measured in considerable detail. These sections, which are given below, afford a good idea of the distribution of the shale in the formation and some idea of its comparative richness.

After most of the distillation tests had been made and the richness of certain kinds of shale had been determined it was found possible to estimate very closely the oil content of any given bed, provided it was clearly exposed. The probable limit of error in such estimates is thought to be less than 20 per cent. Accordingly, in measuring the detailed sections at various places many such estimates were made, and they are given in their appropriate places in the sections.

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[1] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, p. 83, 1910.

Section of part of the middle member of the Green River formation exposed on Parachute Creek, Colo., in sec. 29, T. 5 S., R. 95 W., sixth principal meridian.[1]

	Ft.	in.
Shale, brown, carbonaceous, thin bedded.		
Shale, brown, bituminous; weathers cavernous (estimated to contain 20 gallons of crude oil to the ton)	31	0
Shale, brown, thin bedded, slightly bituminous	5	3
Shale, bituminous	7	3
Shale, fissile; contains some seams of bituminous shale	2	9
Shale, brown		5
Shale, bituminous	1	0
Shale, thin bedded, slightly bituminous		9
Shale, bituminous		3
Shale, thin bedded, slightly bituminous		9
Shale, brown, fine grained, bituminous; estimated	10	0
Shale, brown, thin bedded	26	6
Shale, brown, bituminous (estimated to contain 20 gallons of oil to the ton)	4	10
Shale, brown, thin bedded, fine grained	2	6
Shale, brown, slightly bituminous	5	0
Shale, fissile, fine grained, thin bedded	6	6
Shale, bituminous (sample No. 4, p. 4, obtained from this bed)	5	10
Shale, brown, thin bedded, slightly carbonaceous, moderately calcareous.		
	110	7

Section along Mount Logan trail, Colo., sec. 26, T. 7 S., R. 97 W.

	Ft.	in.
Base of upper member of Green River formation:		
Soil on plateau overlying very sandy brown shale.		
Middle member of Green River formation:		
Shale, bituminous, "curly"	11	0
Shale, very light brown	130	0
Shale, bituminous, "curly"	2	3
Shale, moderately bituminous, bitumen evenly distributed throughout the ledge (estimated to contain 20 gallons of oil to the ton)	81	0
Shale, bituminous		10
Shale, brown, slightly carbonaceous	79	0
Shale, bituminous		13
Shale, brown, slightly bituminous	4	5
Shale, bituminous		8
Shale, brown	2	6
Shale, bituminous		8
Shale, brown, slightly bituminous	12	0
Shale, bituminous		7
Shale, brown, slightly bituminous	3	9
Sandstone		3
Shale, brown		4
Sandstone, brown		4
Shale, brown, slightly bituminous		6

[1] At this place the exposure occurs in a cliff which is so precipitous that the complete section can not be studied in detail. The section is believed to be typical of strata for 200 feet above the portion presented.

	Ft.	in.
Middle member of Green River formation—Continued.		
Shale, bituminous		5
Shale, brown, slightly bituminous	1	2
Shale, bituminous		8
Shale, brown, fissile		8
Shale, bituminous	1	0
Shale, brown, slightly bituminous	3	2
Shale, bituminous (estimated to contain 20 gallons of oil to the ton)	1	1
Shale, brown, slightly bituminous	2	10
Sandstone, brown		8
Shale, brown, slightly bituminous	3	4
Shale, bituminous (estimated to contain 30 gallons of oil to the ton)		8
Shale, brown, slightly bituminous	3	2
Shale, brown, bituminous	9	8
Shale, brown	2	6
Shale, bituminous (estimated to contain 25 gallons of oil to the ton)	2	6
Shale, brown, slightly carbonaceous	1	5
Shale, bituminous (estimated to contain 30 gallons of oil to the ton)		9
Shale, brown, slightly bituminous	2	6
Shale, bituminous	1	0
Shale, brown, slightly bituminous	5	0
Shale, bituminous (estimated to contain 20 gallons of oil to the ton)	5	6
Lower member of Green River formation:		
Shale, gray, thin bedded	122	0
Sandstone, gray	2	0
Shale, gray, fine grained, thin, even bedded; this member seems to be uniform throughout	329	0
Shale, brown, fissile, weathers in flakes as thin as $\frac{1}{32}$ inch	2	6
Shale, drab, fine grained, fissile	178	0
Sandstone, tan		6
Shale, drab, thin bedded; contains thin layers of shaly sandstone	69	0
Sandstone, tan		6
Shale, drab, thin bedded	18	0
Sandstone, tan, slightly irregular in thickness	1	6
Shale, drab, thin bedded	28	0
Sandstone, shaly in lower half	4	0
Shale, thin bedded; this member is uniform throughout except that at intervals of 10 to 20 feet beds of shaly sandstone occur as much as 6 inches thick	174	0
Sandstone, coarse, oolitic	1	6
Sandstone, fine grained, oolitic	1	6
Shale, drab, fissile	63	0
Sandstone, gray	6	0
Shale, gray in upper part, brown in lower, fine grained, fissile	147	0
Shale and sandstone; this member is composed of layers of tan sandy shale and shaly sandstone 6 inches to 2 feet thick	92	0

Lower member of Green River formation—Continued.	Ft.	in.
Sandstone, thick bedded, coarse grained	15	0
Shale, tan, very sandy, with many layers of shaly sandstone some of which are as much as 6 inches thick	98	0
Sandstone, tan, thick bedded	5	0
Shale, tan, sandy; contains layers of shaly sandstone	68	0
Shale, red (top of Wasatch formation).		
	1,806	10

Section of part of the bituminous shale exposed at 4A ranch, Colo., in sec. 21, T. 6 S., R. 99 W.[1]

	Ft.	in.
Shale, bituminous (estimated to contain 20 gallons of oil to the ton)	5	3
Shale		6
Shale, bituminous, "curly"		6
Shale	1	10
Shale, bituminous, "curly"		8
Shale	4	10
Shale, bituminous		8
Shale, carbonaceous, fissile	2	10
Shale, bituminous (estimated to contain 25 gallons of oil to the ton)	1	2
Shale, fissile	1	2
Shale, bituminous (estimated to contain 25 gallons of oil to the ton)		4
Shale, brown, carbonaceous		4
	19	9

Section of part of the middle member of Green River formation on north side of Kimball Creek, sec. 5, T. 7 N., R. 100 W.[2]

	Feet.
Soil and rock débris.	
Shale, bituminous (samples Nos. 2 and 3, p. 4, were taken from 6 feet of this bed from 12 to 18 feet below the top; the upper half of this bed is believed to be slightly richer than the lower half)	48
Shale, locally very calcareous	35
Shale, bituminous	3
Shale, brown, carbonaceous.	
	86

Section of part of Green River formation exposed at Oil tunnel on Whisky Creek, Colo., in sec. 18, T. 5 S., R. 103 W. (approximate location).

Lower member of Green River formation:	Ft.	in.
Shale, tan, fissile		8
Shale, bituminous (same bed as that from which sample No. 8 was obtained; see p. 18.)		4
Shale, tan, fissile	2	0
Shale, tan, sandy	9	0
Sandstone, oolitic	5	0

[1] This section includes only the lower part of the middle member of the Green River formation; 200 feet of similar strata overlie it.

[2] This location is given by a resident of the region who is familiar with the land subdivisions. The writers are inclined to think that the location is in error and that the true location is a few miles east of that given.

Lower member of Green River formation—Continued.	Ft.	in.
Shale, tan, sandy	40	0
Sandstone, oolitic	1	0
Shale, sandy	4	0
Sandstone, oolitic, shaly	2	0
Shale, tan, sandy; shale, brown, carbonaceous, and oolitic sandstone, in beds from 6 inches to 1 foot thick	53	0
Sandstone, oolitic	3	6
Shale, tan	22	0
Covered by talus	21	0
Sandstone, oolitic	6	0
Wasatch formation:		
Shale, tan, sandy	43	0
Sandstone, gray, very porous, petroliferous	13	0
Shale.		
	225	6

Section of lower part of Green River formation at Black Dragon mine, Dragon, Utah.

Soil.	Ft.	in.
Oolite, buff, coarse	6	6
Shale, containing thin beds of sandstone	57	0
Oolite, brown	21	0
Shale, gray	5	4
Sandstone, buff	13	0
Shale, gray	16	0
Oolite, fine grained	5	4
Shale and sandstone	21	0
Oolite, coarse grained	7	2
Shale and sandstone	17	0
Oolite, coarse grained	3	8
Sandstone, buff	4	2
Shale, gray, fine grained	17	0
Oolite, fine grained	1	2
Sandstone, buff, fine grained, weathers cavernous	4	3
Oolite, coarse grained	5	8
Sandstone, buff	50	0
Shale, green, weathers brown	5	0
Oolite, buff, coarse grained	4	0
Sandstone, buff	8	2
Shale, faint green	4	5
Sandstone, light brown	1	0
Shale, gray, weathers cavernous in upper part	6	9
Sandstone, buff, massive, with small lenses of shale intercalated in the sandstone	59	0
Shale, gray, fine grained	12	4
Oolite, buff, coarse grained	26	0
Sandstone, buff, weathers cavernous	22	0
Shale, green, fine grained		3
Sandstone, yellowish; brown below, gray above; massive; weathers cavernous	18	9
Shale, greenish gray, fine grained; this bed is lenticular	14	0
Sandstone, chocolate-brown, thick bedded	13	6
Shale, green, with brown streaks, fine grained, thin lenticular bedding	1	9

	Ft.	in.
Sandstone, light brown, fine grained, in part argillaceous	10	9
Shale, green, fine grained	1	7
Shale, sandy	2	5
Shale, greenish gray, weathers nodular	1	0
Sandstone, dark reddish brown	1	0
Shale, reddish brown, sandy, thin bedded	1	7
Sandstone, reddish brown, fine grained	1	4
Shale, greenish gray, fine grained, weathers nodular	2	0
Sandstone, reddish brown, argillaceous	2	9
Shale, gray, thin bedded	1	5
Sandstone, reddish brown, fine grained, cross-bedded		6
Shale, gray, fine grained	2	7
Sandstone, yellowish brown	2	2
Shale, gray, somewhat arenaceous		6
Sandstone, reddish brown		9
Shale, gray		2
Sandstone, dark brown		2
Shale, gray, sandy in lower part	2	0
Sandstone, brown, fine grained		6
Shale, gray, sandy		4
Sandstone, brown, fine grained		7
Shale, thin bedded	1	6
Sandstone, brown, fine grained, lenticular	2	7
Shale, gray, very sandy	2	2
Sandstone, brown, fine grained; contains lenses of shale	3	4
Shale, gray, fine grained, thin bedded		3
Sandstone, brown, fine grained	3	1
Shale, gray, locally very sandy	8	0
Sandstone, light brown, thick bedded	12	0
Shale, gray, thin bedded, lenticular		5
Sandstone, light brown, fine grained	7	9
Alluvium.		
	529	4

Section on east side of Evacuation Creek, at Ute station on Uintah Railway, Utah.

	Ft.	in.
Sandstone, brown, calcareous; weathers brown; base of upper member of Green River formation.		
Shale, brown, thin bedded	11	0
Limestone, gray, thin bedded	36	0
Shale, gray, calcareous	18	0
Limestone, gray, thin bedded	6	0
Shale, brown, thin bedded, slightly bituminous (possibly contains 2 or 3 gallons of oil to the ton)	165	0
Shale, brown, bituminous		6
Shale, brown, carbonaceous	3	6
Shale, brown, slightly bituminous	1	2
Shale, brown, carbonaceous	3	4
Shale, brown, bituminous		5
Shale, brown, fissile, carbonaceous		5
Shale, brown, bituminous		3
Shale, brown, carbonaceous; weathers gray	62	0
Shale, brown, bituminous		8
Shale, brown; carbonaceous; weathers gray	1	4

	Ft.	in.
Shale, bituminous	1	3
Shale, brown, carbonaceous, thin bedded; weathers gray	12	0
Shale, brown, bituminous		6
Shale, brown, weathers gray, carbonaceous, with seams of bituminous shale half an inch thick in the lower part	5	0
Shale, brown, bituminous	1	10
Shale, brown, carbonaceous	12	0
Shale, brown, bituminous; somewhat variable in bitumen content (sample No. 6, p. 4, collected at Temple station, represents 4 feet of the lower part of this bed)	22	6
Shale, brown, carbonaceous; contains some layers of bituminous shale 1 inch thick	18	6
Sandstone, brown	1	0
Shale, brown, fissile	12	0
Limestone, brown	1	0
Shale, brown, fissile	12	6
Shale, brown, bituminous		8
Shale, brown; weathers tan; fine grained, thin bedded; contains fossil insects	20	0
Shale, brown, bituminous		6
Shale, brown; weathers gray; carbonaceous, very fissile	13	0
Shale, rusty brown, very sandy, calcareous	40	0
Shale, light tan; weathers gray; calcareous	40	0
Sandstone, gray; weathers rusty; thin bedded in lower two-thirds, thick bedded in upper one-third, locally cross-bedded and ripple marked	68	0
Shale, light brown, in layers as thin as 0.1 inch, slightly carbonaceous; 45 feet above base occurs a bituminous shale seam 4 inches thick and another of equal thickness 6 feet higher	58	0
Shale, bituminous		1
Shale, brown, carbonaceous	1	3
Shale, brown, bituminous [1]		1
Shale, brown, carbonaceous		8
Shale, brown, bituminous [1]		1
Shale, brown, carbonaceous		6
Shale, brown, bituminous [1]		2
Shale, brown, carbonaceous		11
Shale, brown, bituminous [1]		2
Shale, brown, carbonaceous		2
Shale, brown, bituminous [1]		2
Shale, brown, locally slightly bituminous	28	0
Shale, brown, bituminous	1	11
Shale, gray, very calcareous	4	0
Shale, brown, bituminous		4
Limestone, gray		9
Shale, very calcareous	3	0
Shale, brown, bituminous		4
Shale, sandy (lower member of Green River formation)	2	0
Water in Evacuation Creek.		
	694	5

[1] These members are included in the Ute station sample, No. 7, p. 4.

Section of strata containing bituminous shale beds on north side of White River, Utah, 5 miles east of White River stage station, T. 9 S., R. 25 E., Salt Lake base and meridian.

	Ft.	in.
Shale, gray, fissile.		
Shale, bituminous		9
Shale, brown, slightly carbonaceous		6
Shale, brown, bituminous		2
Shale, brown, carbonaceous	4	0
Shale, bituminous		3
Shale, brown, carbonaceous		9
Shale, bituminous		8
Shale, brown, fissile, carbonaceous	2	11
Shale, bituminous	1	0
Shale, brown, carbonaceous	1	3
Shale, bituminous (sample of this bed distilled; see samples Nos. 8 and 9, p. 4)	3	6
Shale, brown, carbonaceous	2	4
Shale, bituminous		6
Shale, brown, carbonaceous	3	2
Shale, bituminous		7
Shale, brown, carbonaceous		10
Shale, bituminous		3
Shale, brown, carbonaceous	4	2
Shale, bituminous (estimated to contain 20 gallons of oil to the ton of shale)	6	10
Shale, brown, carbonaceous		11
Shale, bituminous		9
Shale, brown, carbonaceous.		
	36	1

Section of strata containing bituminous shale on Hill Creek, Utah, in sec. 12, T. 13 S., R. 19 E., Salt Lake base and meridian.

	Ft.	in.
Shale, gray, thin bedded.		
Shale, bituminous		8
Shale, brown, carbonaceous	1	7
Shale, brown, thin bedded, calcareous	51	0
Shale, bituminous (see sample No. 11, p. 4)		9
Shale, gray, thin bedded	3	0
Shale, brown, bituminous (contains 15 gallons of oil to the ton of shale)	1	1
Shale, brown, very sandy	1	1
Shale, bituminous; weathers in thin laminæ	5	4
Shale, brown; weathers tan	2	8
Shale, brown, carbonaceous, thin bedded	3	8
Shale, bituminous (estimated to contain 10 gallons of oil to the ton of shale)	1	1
Shale, brown, carbonaceous, thin bedded	4	4
Shale, drab; weathers gray; fissile.		
	76	3

Section of strata containing bituminous shale along freight road from Myton to Price via Harper, Utah, 4 miles north of Ninemile Creek, approximately in sec. 12, T. 11 S., R. 16 E., Salt Lake base and meridian.

	Ft.	in.
Shale, thin bedded, olive-green.		
Shale, brown, bituminous		6
Shale, olive-green, sandy	10	0
Shale, slightly bituminous, weathers in thin layers (sample No. 10, p. 4, was taken from a 6-inch layer near the top of this bed)	4	10
Shale, brown, carbonaceous		6
Shale, bituminous	1	2
Shale, gray, thin bedded	9	0
Shale, brown, slightly bituminous	1	11
Shale, gray, fissile	8	4
Shale, bituminous, weathers fissile (estimated to contain 10 gallons of oil to the ton of shale)	1	2
Shale, gray, sandy	9	0
Shale, brown, carbonaceous	5	6
Shale, olive-green, thin bedded	14	0
Shale, brown, carbonaceous		6
Shale, gray, very sandy	8	0
Shale, brown, carbonaceous		10
Shale, greenish gray, sandy	13	0
Sandstone.		
	88	3

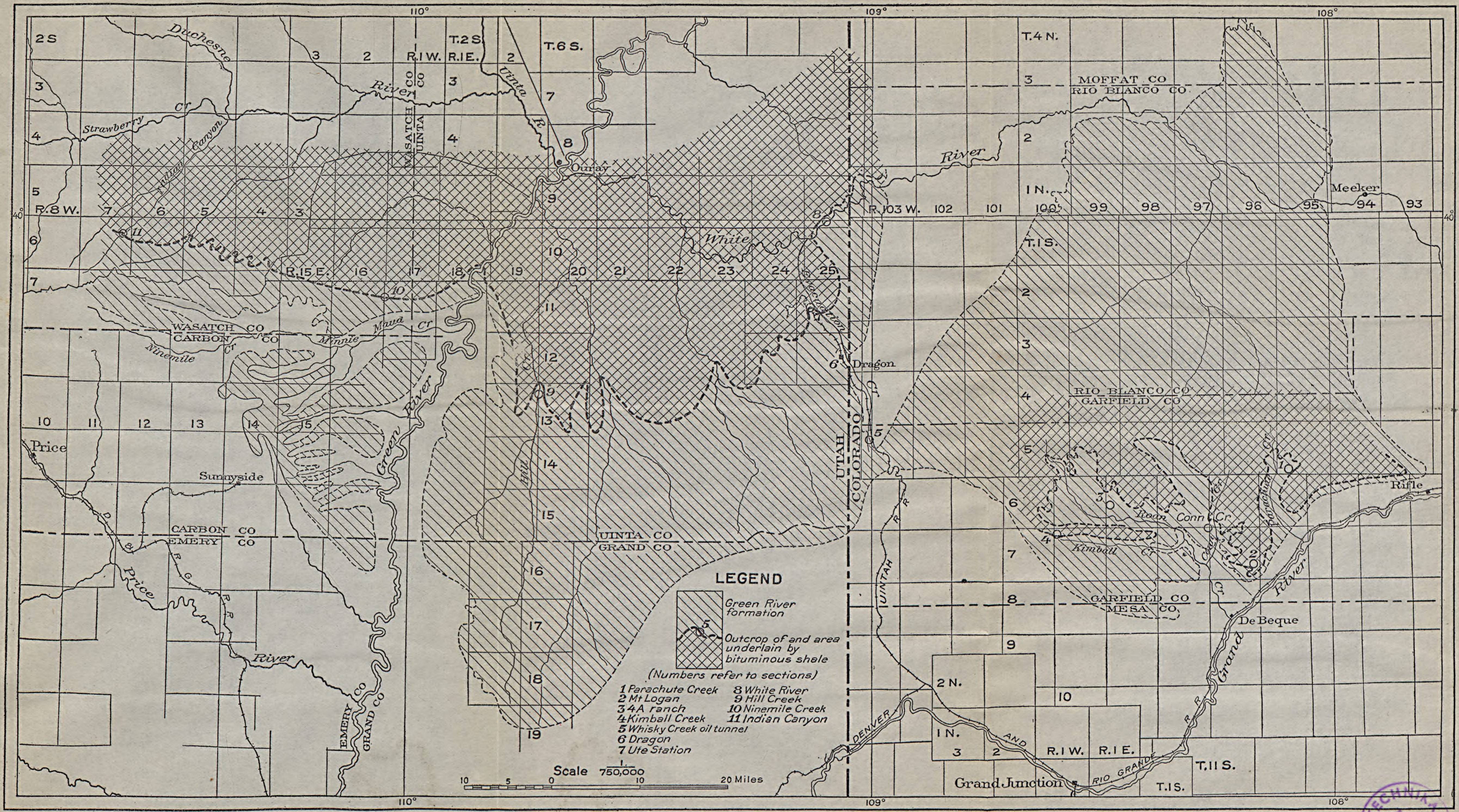
Section of strata containing bituminous shale on west side of Indian Canyon Creek, about 18 miles southwest of Duchesne, Utah, T. 6 S., R. 7 W., Uinta special base and meridian.

	Ft.	in.
Shale, drab, thin bedded.		
Shale, slightly bituminous	2	6
Shale, very sandy		9
Shale, brown, carbonaceous, sandy		8
Shale, drab, thin bedded	71	0
Shale, brown, carbonaceous		7
Shale, drab, thin bedded	7	0
Shale, brown, carbonaceous		6
Shale, drab, fissile.		
	83	0

A sample was taken from an old prospect entry on Conn Creek, Colo., in sec. 1, T. 7 S., R. 98 W. The prospect was opened on what appears to be a lens of bituminous shale, which measures 16 inches in its thickest part. As shown by the field tests described on page 4 and by the laboratory test on page 6, this shale is very rich in hydrocarbons, but it is too thin to be of much commercial value.

STRUCTURE.

The Uinta Basin is a very broad, shallow syncline that lies between the Uinta and Yampa plateaus on the north and the Uncompahgre Plateau, La Salle Mountains, and Beckwith Plateau on the south and extends from the Grand Hogback in Colorado to the Wasatch



MAP OF PARTS OF COLORADO AND UTAH SHOWING PRESENT KNOWN EXTENT OF BITUMINOUS SHALE.

Mountains in Utah. This syncline is divided into an eastern and a western part by a low anticline extending from Dragon, Utah, northward beyond Rangely, Colo.

Minor faults occur at various places. A few in the vicinity of Dragon, Utah, are of the normal type, but the character of the others could not be determined because of the reconnaissance nature of the work. The area seems to have been involved in a broad gentle structural movement, with the local intensive action evident. It is probable that some crustal movements formed the fissures in which the remarkable veins of gilsonite occur, but as yet no conclusive explanation of the origin of the gilsonite has been offered.

In areas occupied by bituminous shale the beds are either horizontal or only slightly inclined. In that part of the Colorado area that was surveyed the rocks dip gently to the north, except in the southeastern part, where they are horizontal. In Utah also the strata dip to the north but at slightly greater angles, though at no place are the dips greater than 14°.

BURNING OF SHALE ALONG THE OUTCROP.

Near Rowley's ranch, on Parachute Creek, 8 miles northwest of Grand Valley, Colo., the cliffs are strewn with slag produced by the burning of the bituminous matter in the shale. The burning appears not to have extended for more than one-fourth mile along the escarpment nor to have penetrated beyond 300 feet in depth, as shown in valleys that have been eroded through the clinker. Burning seems not to have been so intense as in some of the coal beds of this region, but the rocks have reached a temperature high enough to bake the shale to pink, red, or yellow and locally to fuse it to a slag. The burning shows that the shale carries a high percentage of bitumen, else the action could not have taken place.

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