Tertiary Geology and Oil-Shale Resources of the Piceance Creek Basin Between the Colorado and White Rivers Northwestern Colorado

By JOHN R. DONNELL

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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TERTIARY GEOLOGY AND OIL-SHALE RESOURCES OF THE PICEANCE CREEK BASIN BETWEEN THE COLORADO AND WHITE RIVERS, NORTHWESTERN COLORADO

By John R. Donnell

ABSTRACT

The area of the Piceance Creek basin between the Colorado and White Rivers includes approximately 1,600 square miles and is characterized by an extensive plateau that rises 1,000 to more than 4,000 feet above the surrounding lowlands. Relief is greatest in Naval Oil-Shale Reserves Nos. 1 and 3 near the south margin of the area, where the spectacular Roan Cliffs tower above the valley of the Colorado River.

The oldest rocks exposed in the mapped area are sandstone, shale, and coal beds of the Mesaverde group of Late Cretaceous age, which crop out along the east margin of the area. Overlying the Mesaverde is an unnamed sequence of dark-colored sandstone and shale, Paleocene in age. The Ohio Creek conglomerate, composed of black and red chert and quartzite pebbles in a white sandstone matrix, is probably the basal unit in the Paleocene sequence. The Wasatch formation of early Eocene age overlies the Paleocene sedimentary rocks. It is composed of brightly colored shale, lenticular beds of sandstone, and a few thin beds of fresh-water limestone. The Kasatch formation interfingers with and is overlain by the Green River formation of middle Eocene age.

The Green River formation has been divided into the Douglas Creek, Garden Gulch, Anvil Points, Parachute Creek, and Evacuation Creek members. The basal and uppermost members, the Douglas Creek and Evacuation Creek, respectively, are predominantly sandy units. The two middle members, the Garden Gulch and Parachute Creek, are composed principally of finer clastic rocks. The Anvil Points member is present only on the southeast, east, and northeast margins of the area. It is a nearshore facies composed principally of sandstone and is the equivalent of the Douglas Creek, Garden Gulch, and the lower part of the Parachute Creek members.

All of the richer exposed oil-shale beds are found in the Parachute Creek member, which is divided into two oil-shale zones by a series of low-grade oil-shale beds. The upper oil-shale zone has several key beds and zones which can be traced throughout most of the mapped area. One of these, the Mahogany ledge or zone, is a group of very rich oil-shale beds at the base of the upper oil-shale zone. Drilling for oil and gas in the northeastern part of the area has revealed rich oil-shale zones in the Garden Gulch member also.

Local unconformities within and at the base of the Evacuation Creek member are exposed at several places along Piceance Creek and at one place near the mouth of Yellow Creek; otherwise, the rock sequence is conformable.

The mapped area is the major part of a large syncline, modified by numerous smaller structural features. Fractures, probably associated genetically with the minor structural features, are present in the central part of the area. These fractures are high-angle normal faults with small displacement. They occur in pairs with the intervening block downdropped. Two sets of joints are prominent, one trending northwest and the other northeast. The joint systems control the drainage pattern in the south-central part of the area.

More than 20,000 feet of sedimentary rocks underlies the area. Many of the formations yield oil or gas in northwestern Colorado, northeastern Utah, and southwestern Wyoming. The Piceance Creek gas field, in which gas occurs in the Douglas Creek member of the Green River formation, is the largest oil or gas field discovered thus far within the area.

About 7,000 million barrels of oil is contained in oil shale that yields an average of 45 gallons per ton from a continuous sequence 5 or more feet thick in the Mahogany zone. Oil shale in the Mahogany zone and adjacent beds that yields an average of 30 gallons of oil per ton from a continuous sequence 15 or more feet thick contains about 91,000 million barrels of oil. Similar shale in deeper zones in the northern part of the area, for which detailed estimates have not been prepared, are now known to contain at least an additional 72,000 million barrels of oil. Oil shale in a sequence 15 or more feet thick that yields an average of 25 gallons of oil per ton contains about 154,000 million barrels of oil in the Mahogany zone and adjacent beds; such shale in deeper zones in the northern part of the area probably contains at least an additional 157,000 million barrels of oil, although detailed estimates were not made. Oil shale in a sequence greater than 15 feet thick that yields an average of 15 gallons of oil per ton contains more than 900,000 million barrels of oil. These estimates of the oil content of the deposit do not take into account any loss in mining or processing of the shale.

INTRODUCTION

LOCATION OF AREA

The Piceance Creek basin is a large northwest-trending structural downwarp in northwestern Colorado. This report describes that part of the basin lying between the Colorado and White Rivers (fig. 71), an area of about 1,600 square miles in Mesa, Garfield, and Rio Blanco Counties.

PURPOSE OF THE INVESTIGATION

The greatest known potential oil resource in the world occurs in the oil shale of the Green River formation, and the richest and thickest deposits occur within the area of this report. The purpose of this investigation was to obtain data on the stratigraphic distribution and areal extent of the oil-shale beds and to estimate the potential oil resources in the area.

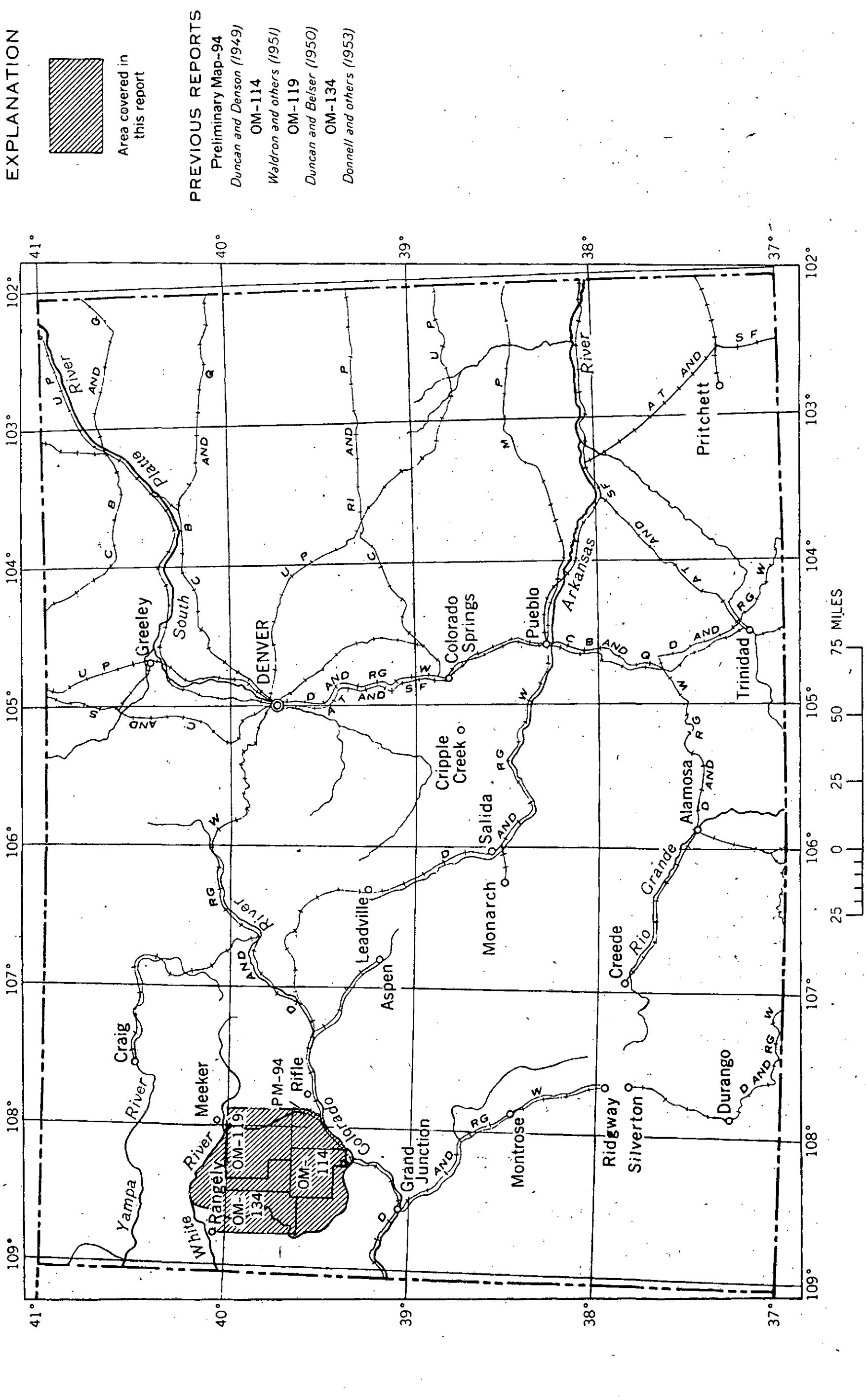


Figure 71.—Index map of Colorado showing location of mapped area.

GEOGRAPHY

Most of the area is a plateau that rises from 1,000 to more than 4,000 feet above the surrounding lowlands. Altitudes range from 4,900 feet on the Colorado River near De Beque to 9,400 feet at the crest of the cliffs that tower above Rifle. The southern part of the plateau has been deeply dissected (pl. 55) and terminates in a very irregular line of spectacular precipitous cliffs, the Roan Cliffs. Elsewhere the rim of the plateau is more regular and less precipitous, although the Cathedral Bluffs along the northwest edge of the plateau are notably sheer. In general, the land surface slopes gently downward from the rim toward the central part of the plateau, and most of the central part of the plateau is characterized by rough rolling hills. The Roan Plateau, a lightly dissected broad drainage divide, crosses the south-central part of the area from east to west, and the extension of this highland westward into Utah forms the only interruption to the rim of cliffs.

The northern and larger part of the area is drained by tributaries of the White River, principally Piceance and Yellow Creeks. The southern part of the area is drained by tributaries of the Colorado River, principally Roan and Parachute Creeks. These major perennial streams are supplied by springs that originate at or near the contact of the oil-shale sequence with the overlying sandstone.

Recorded mean annual precipitation in the area averages about 10 inches per year. However, the rain gages are located in towns, all of which are less than 6,300 feet in altitude. Probably most of the plateau receives considerably more rainfall, as its average altitude exceeds 7,000 feet.

Vegetation over most of the plateau is sparse; and sage, piñon, and juniper are the most representative plant types. North-facing slopes and local patches elsewhere support more dense vegetation and steep slopes along the north and east margins of the basin are covered with a heavy growth of scrub oak and buckbrush, interrupted at 5- to 10-mile intervals by canyons which provide fair to excellent exposures of the rock sequence. Scattered groves of aspen, lodgepole pine, and blue spruce grow in the higher parts of the Roan Plateau.

INDUSTRY

The principal industry in the area is stock raising, and ranches are scattered throughout the mapped area. Ranchers lease parts of the high plateau, mostly government land, for summer grazing and use the valley bottoms for winter grazing.

The Piceance Creek gas field, in which there are 10 shut-in gas wells, is in the east-central part of the mapped area.

The U.S. Bureau of Mines in 1945 established an experimental oil-shale mine and retort at Anvil Points in the southern part of Naval Oil-Shale Reserves Nos. 1 and 3, about 9 miles west of Rifle, Colo. Here the Bureau of Mines devised methods of mining and retorting shale.

POPULATION

Rifle, Colo., 2½ miles southeast of the mapped area, has a population of approximately 1,500 and is the largest town in the immediate vicinity. It is the supply center for ranches in central Garfield County. The town of Grand Valley, with a population of about 400, is at the mouth of Parachute Creek near the center of the southern part of the area, and it supplies the ranchers in the Parachute Creek area. De Beque, with a population of about 400, is 16 miles west of Grand Valley and supplies the ranchers of Roan Creek and its tributaries. Meeker, the county seat of Rio Blanco County, is 4 miles east of the northeast corner of the mapped area. It has a population of about 1,600 and is the supply center for the area drained by the upper White River. Rangely, a town of about 800 people, is about 12 miles northwest of the mapped area and is in the southern part of the Rangely oil field, the largest oil field in Colorado. Rangely is the supply center for the western part of Rio Blanco County.

ACCESSIBILITY

U.S. Highways 6 and 24 and the main line of The Denver and Rio Grande Western Railroad follow the north bank of the Colorado River across the southern part of the mapped area. Graded county roads lead from the highway up Roan and Parachute Creeks and their tributaries, ending abruptly at the heads of the valleys where sheer cliffs render further vehicular travel impossible. Many trails ascend the steep slopes and afford access to the Roan Plateau from the south by pack horse. State Highway 13, between Meeker and Rifle, skirts the eastern boundary of the mapped area. State Highway 326, an unpaved but well-graded road, leads from State Highway 13 at Rio Blanco, 20 miles north of Rifle, northwest down the valley of Piceance Creek. A number of well-graded county roads and bulldozed stock roads branch from State Highway 326 and afford easy access to most of the plateau. At its north terminus, State Highway 326 connects with U.S. Highway 64, which follows the White River to Rangely. A well-graded private road leads from U.S. Highway 64 into the north part of the mapped area in the vicinity of Yellow Creek.

PREVIOUS INVESTIGATIONS

In 1874 the Green River group was recognized along the Colorado River in the Piceance Creek basin during one of the Hayden surveys (Peale, 1876), and 2 years later a reconnaissance map was made of the Green River strata in a part of the area drained by the Colorado River (Peale, 1878). Eldridge (1901, p. 334, table 4) first called attention to the oil-shale beds of the Green River formation, stating that the formation contains "shales and limestones, bituminous, locally in a degree to be of economic value." In 1913 a reconnaissance survey of the oil-shale deposits of part of Colorado and Utah was conducted by Woodruff and Day (1914). Field and laboratory tests of oil-shale samples from scattered localities to determine the oil content of the shale were made in conjunction with field mapping. Winchester (1916, 1923) carried on field investigations and assayed numerous oil-shale samples over the period 1913–18 in order to estimate more fully the oil-producing potentialities of the shale in Colorado, Utah, and Wyoming. It is largely on the basis of his conclusions that Naval Oil-Shale Reserves Nos. 1 and 3 in northwestern Colorado, and Naval Oil-Shale Reserve No. 2 in northeastern Utah were established. In 1924 and 1925, Bradley (1931) made a detailed examination of the paleontology and stratigraphy of the Green River formation in Colorado and Utah.

In the summer and fall of 1945 a field party of the U.S. Geological Survey mapped Naval Oil-Shale Reserves Nos. 1 and 3 and adjacent areas for the U.S. Navy (Duncan and Denson, 1949). At this time several surface sections were sampled and the samples assayed by the U.S. Bureau of Mines for oil content. The Bureau of Mines also drilled and assayed core from four drill holes. In 1948 approximately 375 square miles adjacent to Naval Oil-Shale Reserves Nos. 1 and 3 and immediately north of De Beque, Colo., was mapped in detail by the U.S. Geological Survey (Waldron, Donnell, and Wright, 1951). Duncan and Belser (1950) reported the results of a study of the samples of 4 gas wells and 1 surface section in the eastern part of the area. The U.S. Geological Survey mapped the Cathedral Bluffs area, an area of 385 square miles north of the De Beque oil-shale area, in 1949 (Donnell, Cashion, and Brown, 1953).

PRESENT INVESTIGATION

This report and the accompanying geologic map (pl. 48) is a compilation of the geologic information contained in published reports by Duncan and Denson (1949), Duncan and Belser (1950), Waldron, Donnell, and Wright (1951), and Donnell, Cashion, and Brown (1953) (fig. 71), together with the heretofore unpublished results of geologic mapping and field investigation in the summer of 1950 by J. R. Donnell, W. B. Cashion, Jr., J. H. Brown, Jr., and W. M. Zilbersher, and in the summer of 1951 by J. R. Donnell and Kenneth Englund.

Geologic contacts in the De Beque area were drawn and a map (Waldron, Donnell, and Wright, 1951) was published on a topographic base comprising parts of the Highmore, Parachute Creek, Roan Creek, and Grand Valley quadrangles; in Naval Oil-Shale Reserves Nos. 1 and 3 the contacts were drawn and a map (Duncan and Denson, 1949) was published on a more detailed topographic base; in the remainder of the area the geologic contacts were mapped on aerial mosaics prepared by the Soil Conservation Service, U.S. Department of Agriculture. Altitudes were obtained on key beds in the middle members of the Green River formation by means of planetable and alidade or aneroid barometer. Structural control was good in Naval Oil-Shale Reserves Nos. 1 and 3, in the De Beque area, and in the western part of the Cathedral Bluffs area, and structure-contour maps of these areas were made to show the minor structural anomalies along the south and west edge of the major structural basin. Good datum beds for structural mapping were not found in the remainder of the area; consequently a structure map of the entire area was not compiled.

ACKNOWLEDGMENTS

The writer is indebted to Tell Ertl and the Union Oil Co. of California; Charles Ethrington and the Standard Oil Co. of California; L. W. Storm and the Sun Oil Co.; and John Savage, Charles Prien, and the Institute of Industrial Research of the University of Denver for the opportunity to examine cores and for furnishing analyses of the oil content of the cores. Analyses of cores were also furnished by the U.S. Bureau of Mines and J. T. Juhan. The General Petroleum Corp. granted permission to use analyses of cuttings from most of the gas wells in the Piceance Creek field in the computation of oil-shale resources of the area. W. O. Pray, a resident of De Beque who has done much work on oil shale in the area around De Beque, furnished analyses of the rich oil shale in the southwestern part of the area along the ridge between Roan and Kimball Creeks and called attention to the presence of considerable oil in the lower ostracodal shale several hundred feet above the base of the Green River formation. Carl Belser, of the U.S. Bureau of Mines, furnished analyses of all oil-shale samples that he obtained. Roland W. Brown and T. C. Yen of the U.S. Geological Survey identified the fossils that were collected. The fieldwork and office compilation of the report were under the general supervision of N. W. Bass and A. D. Zapp.

STRATIGRAPHY

Rocks of Tertiary and Late Cretaceous age are exposed within the area of this report. The oldest rocks mapped are the sandstone, shale, and coal beds of the Mesaverde group of Late Cretaceous age. An indeterminate thickness of rocks of Paleocene age, believed to be the equivalent of part of the Fort Union formation, overlies the Mesaverde group in much of the area. A thick series of sandstone and brightly colored shale that comprise the Wasatch formation of early Eocene age conformably overlies the Paleocene rocks. The youngest sedimentary rocks in the mapped area are sandstone, shale, and marlstone beds of the Green River formation of middle Eocene age. The Green River strata are the surface rocks throughout the greater part of the mapped area. The uppermost 400 feet of the Green River formation in the north-central part of the area consists of massive fine-grained to medium-grained generally contorted sandstone interbedded with lenticular beds of white siltstone and marlstone. These beds were tentatively assigned to the Bridger formation by Bradley (1931, p. 19) on the basis of lithologic similarity. Attempts to map these beds as a separate formation were not successful during this investigation because there is no consistent and mappable change in lithology. Hence they are here included in the Green River formation.

CRETACEOUS SYSTEM

UPPER CRETACEOUS SERIES

MESAVERDE GROUP

The Mesaverde group crops out almost continuously around the margins of the Piceance Creek basin. The Mesaverde rocks are resistant to erosion, and form prominent benches, ridges, or cliffs. The Grand Hogback (fig. 73), a very prominent ridge along the east margin of the mapped area, and the Book Cliffs, a short distance southwest of the mapped area, are formed by these rocks.

The Mesaverde group was not studied during this investigation, and fieldwork was limited to mapping the upper boundary of the group along the east margin of the area. The most conspicuous lithologic component of the Mesaverde group is fine- to coarse-grained sandstone, though there is much interbedded shale and sandy shale and, generally, several coal beds.

The thickness of the Mesaverde group apparently decreases toward the west. The greatest reported thickness in the mapped area is about 5,600 feet, measured by Gale (1910, pl. 6) in the vicinity of upper Piceance Creek near the center of the east margin of the area of this report. Along Douglas Creek, just west of the mapped area, Gale (1910, pl. 20) reported a thickness of 2,500 feet. Just north of the mapped area, a well, the Union Oil of California–Frontier Refining Unit 1 well in sec. 30, T. 2 N., R. 96 W., was drilled through about 4,000 feet of the Mesaverde. Near the south margin of the area the Phillips Petroleum–Pray Govt. 1 well, sec. 31, T. 8 S., R. 98 W., penetrated a thickness of 3,000 feet.

The Mesaverde rocks north, northwest, and northeast of the area were divided into lower and upper units by Gale (1910, p. 63–71), and these units were later designated, respectively, the Iles and Williams Fork formations by Hancock (1925, p. 14.) Erdmann (1934, p. 32–33) divided the Mesaverde group into three formations in the area just southwest of the area of this report. They are, in order of decreasing age, the Sego sandstone, the Mount Garfield formation, and the Hunter Canyon formation. The correlation of the various subdivisions of the Mesaverde across the Piceance Creek basin has not been established.

The fossil content of various beds in the Mesaverde group indicates that some of the sediments were deposited in fresh water, others in brackish water, and still others in marine water. Much of the sediment apparently accumulated at or near ancient strand lines.

TERTIARY SYSTEM

PALEOCENE(?) SERIES

OHIO CREEK CONGLOMERATE

A thin zone of conglomerate and associated coarse sandstone, which the writer considers correlative with the Ohio Creek conglomerate of areas to the south (Lee, 1912, p. 18, 48–49), overlies the Mesaverde group along the east margin of the area. The conglomerate was also observed just south of the mapped area, at the mouth of De Beque Canyon in the NW¼ sec. 16, T. 9 S., R. 97 W., but was not found in the western part of the area. However, it was found in drilling as far west as sec. 30, T. 2 N., R. 96 W., in wells drilled on the White River dome by the Union Oil Co. of California and the Frontier Refining Co.

The conglomerate is composed mostly of pebbles and cobbles of red and black chert and quartzite ranging from the size of a pea to 4 or 5 inches in diameter. At all exposures examined the cobbles and pebbles are associated with poorly indurated coarse-grained white sandstone (pl. 56); at places they occur within the white sandstone and at other places in a brown sandstone matrix either just above or just below the white sandstone.

The observed range in thickness of the conglomerate in the area is from 5 feet at a locality in T. 9 S., R. 97 W. to about 20 feet on U.S. Highway 64, 3 miles west of Meeker.

The lower and upper contacts of the Ohio Creek conglomerate apparently are conformable. No fossils have been reported from the conglomerate, so that the age of the formation is not known. The conglomerate is assigned to the Paleocene(?) because of its affinities with overlying beds of established Paleocene age.

Plant and animal remains indicating deposition in a continental environment have been found within short stratigraphic distances above and below the Ohio Creek conglomerate, and a similar mode of origin is assumed for the conglomerate.

The Ohio Creek conglomerate and the overlying unnamed unit of Paleocene age were included with the Wasatch formation in geologic mapping.

PALEOCENE SERIES

UNNAMED UNIT

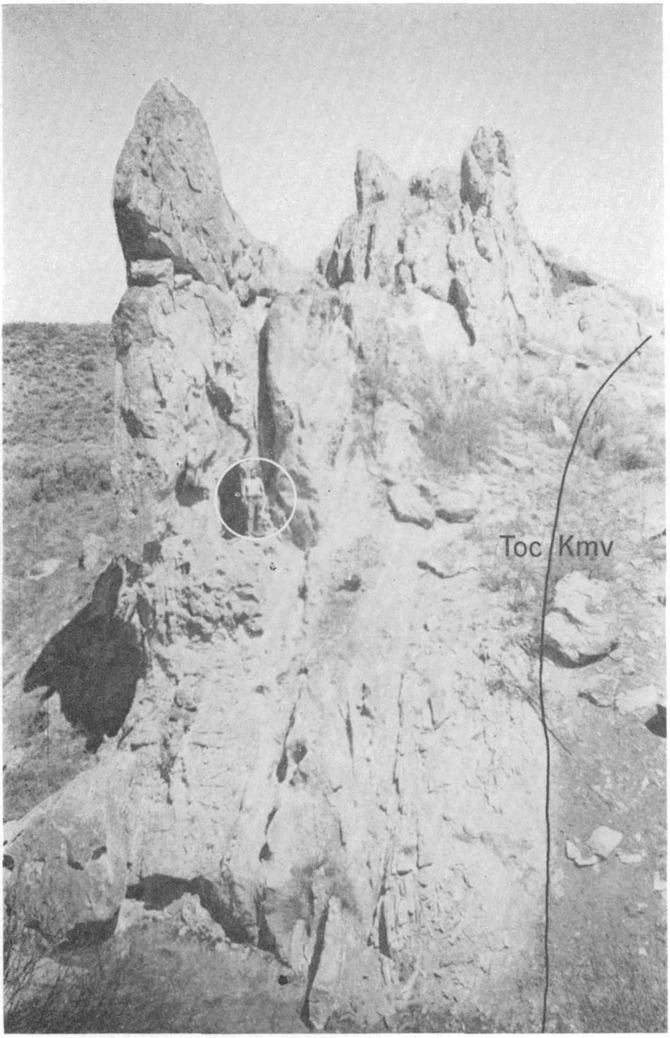
A sequence of brown sandstone and somber-colored shale which has yielded remains of plants and animals of Paleocene age in and near the mapped area, and which probably is correlative with a part of the Fort Union formation of the northern Rocky Mountain region, overlies the Ohio Creek conglomerate. The unit was observed on all sides of the area and presumably underlies the entire area.

Massive brown and gray poorly consolidated feldspathic sandstone beds, gray and brown clay and shale beds, and a few thin coal beds are the principal components of this unnamed unit. These persistent ledge-forming sandstone beds, coal beds, and drab clay and shale beds contrast markedly with the overlying lenticular sandstone and brightly colored clay and shale beds in the lower part of the Wasatch formation.

These rocks between the Mesaverde group and the Wasatch formation range in thickness from a little more than 500 feet along the Grand Hogback, about 13 miles north of Rifle, to 0 in the southwestern part of the area.

Plant remains of Fort Union (Paleocene) age were identified from these beds by F. H. Knowlton (Gale, 1910, p. 79). The collection was from a locality near the center of the west line of T. 5 S., R. 92 W. The general locality was visited during the present investigation, and the fossiliferous bed was found to be approximately 200 feet above the top of the Ohio Creek conglomerate. Plant remains were collected at a locality in the NW¼ sec. 16, T. 9 S., R. 97 W., along the south side of the highway at the east entrance to De Beque Can-

AERIAL VIEW OF ROAN CLIFFS ALONG PARACHUTE CREEK
Oblique view upstream. U.S. Army Air Force photograph, July 21, 1947.



OHIO CREEK CONGLOMERATE

Steeply dipping brown sandstone of the Ohio Creek conglomerate (*Toc*) overlying the white sandstone in the Mesaverde group (*Kmv*). Exposure is near State Highway 13, about 10 miles south of Meeker, Colo.

yon. Roland W. Brown identified the following Paleocene forms from this collection:

Carya antiquorum Newberry
Ficus planicostata Lesquereux
Platanus sp.
Fragments of other dicotyledons.

Shells of nonmarine mollusks were collected from a massive gray sandstone unit that resembles the Mesaverde in lithology near the west margin of the area, in the SW¼ sec. 24, T. 3 S., R. 100 W. T. C. Yen identified the following from this collection:

Unio sp. undet.
Viviparus sp. undet.
Lioplacodes cf. *L. tenuicarinata* (Meek and Hayden)
Hydrobia cf. *H. utahensis* White
Goniobasis sp. undet.
"*Planorbis*" sp. undet.
Lymnaea sp. undet.

Mr. Yen stated: "The mollusca-bearing bed is possibly of upper Paleocene age and possibly equivalent to the uppermost part of the Fort Union formation." Another collection of nonmarine mollusks from a horizon 75 feet higher and just above a series of thin coal beds was examined by Mr. Yen. He considered this fauna, which included *Goniobasis* cf. *tenera* (Hall) and *Anisus cirrus* (White), to indicate a probable early Eocene age.

Vertebrate fossils have not been reported from this series of beds in the mapped area; however, upper Paleocene vertebrate remains have been described from apparently equivalent beds in the valley of Plateau Creek, about 18 miles south of Grand Valley (Patterson, 1939).

The unit rests conformably and in places gradationally upon the Ohio Creek conglomerate in the eastern and southern parts of the area. On the west, the contact between the unit and the Mesaverde group is obscure. The upper boundary of the unit has not been fixed, for the darker beds generally grade imperceptibly into lenticular sandstone beds and brightly colored shale of the Wasatch formation.

The unit has not been named and has not been separately mapped because of the lack of suitable boundaries. Patterson (1936, p. 397) has referred to probably equivalent beds south of the area as the Plateau Valley beds. This name was used for beds of Paleocene age, but no lithologic definition was given. Patterson (1934, fig. 13), in an earlier publication, placed the top of the Paleocene at the base of a thick unit of massive sandstone, although fossils assigned to the Paleocene were found in only the lowermost part of the underlying shaly unit. During the present investigation, the massive sandstone unit was found to be present only within a radius of approximately 10 miles of De Beque and inasmuch as it is underlain by brightly colored shale lithologically typical of the Wasatch formation, it is treated in this report as a local middle member of the Wasatch.

The unnamed unit of Paleocene age is of nonmarine origin, as shown by its organic content. The local presence of thin coal beds indicates the existence of scattered short-lived swamps.

EOCENE SERIES

WASATCH FORMATION

The brightly colored beds of the Wasatch formation crop out almost continuously around the margins of the area. The Wasatch rocks are generally nonresistant, and their belt of outcrop forms a lowland between the cliffs or ridges of the Green River formation and the Mesaverde group.

The Wasatch formation in the area consists mostly of brightly colored clay and shale. Shades of red predominate, but purple, gray, green, lavender, and yellow are common. Lenticular sandstone is present nearly everywhere, and locally it is a prominent component. Local minor lithologic components are conglomerate, pebbly sandstone, limestone, coal, and black carbonaceous shale.

The thickness of the Wasatch formation varies greatly, with an overall thinning toward the west. The greatest reported thickness in the area is 5,500 feet, drilled in the General Petroleum well 84-15-G in sec. 15, T. 2 S., R. 96 W. A thickness of 5,300 feet was measured about 10 miles northwest of Rifle, on State Highway 13. Gale (1910, p. 82) reported a thickness of 3,400 feet a short distance to the north of this locality, along Piceance Creek near Rio Blanco. The Wasatch is 2,000 feet thick along Horsethief Creek, about 5 miles south of De Beque, and is 800 feet thick about 18 miles farther northwest, along upper Coal Creek in T. 8 S., R. 100 W. Only 375 feet of Wasatch was measured in the northwestern part of the area, on Big Spring Creek in sec. 28, T. 1 N., R. 100 W. These thickness figures include the unnamed Paleocene strata at the base.

Within a radius of 10 miles of De Beque, the Wasatch formation has a tripartite character owing to the presence of a middle unit of cliff-forming sandstone beds beginning about 700 feet above the base of the formation. The sandstone unit is composed chiefly of massive brown sandstone beds, with some thin zones containing black chert pebbles in a white sandstone matrix, and minor beds of greenish clay. Some of the sandstone beds are unusually persistent. North, east, and west of its northernmost exposure, just north of the Colorado River midway between De Beque and Grand Valley, the sandstone units passes under younger rocks. At this horizon in the next exposure to the east, the sandstone unit is not present, and it is not known whether it disappears by wedging out or by lateral gradation to shale. A series of sandstone beds in the area north of Rifle may represent a correlative unit.

In the northwestern and western parts of the area, west and southwest from the vicinity of Yellow Creek, the Wasatch formation is somewhat different in character than in the remainder of the area. Dull-colored gray to tan shale and brown sandstone predominate, and few zones exhibit the typical reddish colors.

The base of the Wasatch formation is indefinite, for there is a gradual transition downward into the somber-colored beds of Paleocene age. The upper contact is generally placed where the irregularly bedded and brightly colored sedimentary rocks give way to more regularly bedded and nonred rocks, generally sandstone, of the Green River formation. The color change is the principal criterion used in selecting the boundary. In many places this contact is transitional. In the vicinity of Yellow Creek the contact was placed at the base of the lowest massive sandstone which overlies a thick sequence of varicolored shale.

The Wasatch formation of this and adjacent areas has yielded numerous fossils which indicate that it is of early Eocene age and that the sediments accumulated in a dominantly fluviatile environment.

GREEN RIVER FORMATION

Sedimentary rocks of the Green River formation are the surface rocks over most of the area of this report, as they cap the great dissected plateau that generally terminates in sheer cliffs. The predominantly white color of these cliffs contrasts with the bright colors of the underlying Wasatch formation.

Post-Green River rocks have been removed from the area by erosion, so that the total original thickness of the Green River formation is not known. A maximum of more than 3,000 feet of the formation is present in the northeastern part of the area.

The Green River formation is composed predominantly of dark shale and magnesian marlstone, some of which yields oil on distillation. These beds weather to shades of light gray, light blue gray, or light brown, with a definite whitish aspect. Sandstone, siltstone, limestone, and oolite are other lithologic components which are prominent in parts of the formation. The formation as a whole is characterized by remarkably regular thin bedding and remarkable lateral persistence of some of the thin units.

In the southwestern part of the area, the formation is divisible into four lithologic units. The basal unit is characterized by a relatively large amount of sandstone, limestone, and oolite; the next higher is composed predominantly of finely laminated shale; the third is characterized by its relatively large amount of oil shale; the uppermost unit contains considerable sandstone. These units were named the Douglas Creek, Garden Gulch, Parachute Creek, and Evacuation Creek members, respectively, by Bradley (1931, p. 9). Mapping of these members during the present investigation revealed considerable variation in thickness of the various members, with one member thickening at the expense of one or both adjacent members, but the fourfold division was found to be mappable over much of the west half of the area. The Douglas Creek member disappears as a lithologic unit through lateral gradation in T. 1 N., R. 100 W., and north and east from that point for a considerable distance around the north rim of the plateau, rocks of Garden Gulch lithology form the basal unit of the formation. The Douglas Creek member also wedges out in the southwestern part of the area, and the Garden Gulch member overlies the Wasatch formation. From the vicinity of Grand Valley northward around the eastern part of the area to the vicinity of the mouth of Piceance Creek, the rocks equivalent to the Douglas Creek and Garden Gulch members and the lowermost part of the Parachute Creek member of areas to the west were found to be a relatively homogeneous sandy unit which is here named the Anvil Points member. The thickness, lithology, and stratigraphic relations of the members of the Green River formation in various parts of the area are shown graphically in plates 49–53.

The formation in general represents a continuous depositional unit, and the contacts between the several members are generally conformable and gradational. Local structural discordance between the Parachute Creek and Evacuation Creek members was noted in the northern part of the area (p. 861).

The sedimentary structures and textures, mineralogy, and fossil content of the Green River formation and its various members are described in detail by Bradley (1931) and Stanfield and others (1951). The physical features and organic content of the formation indicate that it was deposited in a great lake that existed during the middle part of the Eocene epoch.

DOUGLAS CREEK MEMBER

The Douglas Creek member is recognizable at the outcrop only in the southern and western part of the area. In T. 1 N., R. 100 W., it grades northward into shale of the Garden Gulch member, and northeast of Grand Valley the rocks equivalent to the Douglas Creek member are included in the Anvil Points member. In the subsurface the Douglas Creek member has been recognized as far northeast as the Piceance Creek gas field in Tps. 1 and 2 S., Rs. 95 and 96 W. (Duncan and Belser, 1950.) Northwest of the gas field it is apparently replaced by shale of the Garden Gulch member, for it is absent in the General Petroleum well 64–8–G in sec. 8, T. 1 N., R. 98 W.

The rocks of the Douglas Creek member are resistant to erosion and commonly form a series of benches in the lower part of the Green River escarpment. The member is made up mostly of crossbedded and ripple-marked sandstone, algal and ostracodal limestone, and oolitic sandstone and limestone, with minor amounts of gray shale. It is predominantly brown to buff.

The member attains a maximum thickness of nearly 800 feet in the type section at the head of Trail Creek near the center of T. 4 S., R. 101 W., just west of the area of this report. Along Parachute Creek it ranges from 430 to 470 feet in thickness (Duncan and Denson, 1949); a short distance west, on lower Clear Creek, it is 410 feet thick. It ranges, in the subsurface, from 22 feet in thickness in the General Petroleum well 51–28, in sec. 28, T. 1 S., R. 97 W., to a maximum drilled thickness of 184 feet in the General Petroleum Well 27–8–G in sec. 8, T. 2 S., R. 95 W.

The Douglas Creek member conformably overlies the brightly colored Wasatch formation. At many places the contact is transitional. The Douglas Creek member is conformably overlain by the Garden Gulch member.

GARDEN GULCH MEMBER

The Garden Gulch member crops out in gray steep slopes between the brown and buff benches of the Douglas Creek member and the precipitous whitish cliffs of the Parachute Creek member. The Garden Gulch member was mapped from the Parachute Creek valley around the western margin of the plateau to a point between the mouths of Yellow and Piceance Creeks on the north rim. Along the east rim, sandy beds equivalent to the Garden Gulch member are included in the Anvil Points member. In the subsurface, the Garden Gulch member is typically developed as far northeast as the Piceance Creek gas field in T. 2 N., Rs. 95 and 96 W., so it undoubtedly underlies most of the area.

The Garden Gulch member is characterized by much papery to flaky shale. Marlstone, generally barren of oil, is a prominent lithologic component of the member. Thin beds of sandstone, oil-shale breccia, and ostracodal, oolitic, and algal limestone are locally present. In the Yellow Creek area there is a 10-foot quartz-pebble conglomerate unit in the upper part of the member. Barren marlstone, locally with prominent beds of algal limestone and sandstone, predominates in the southwestern part of the area. Cuttings from wells in the Piceance Creek gas field show that the member there consists almost entirely of shale.

At the type locality in the northwestern part of T. 6 S., R. 96 W., the Garden Gulch member is 700 feet thick, and at the head of Coal Creek, in the northwestern part of T. 8 S., R. 100 W., it is 900 feet thick. Here the Douglas Creek member is absent and the Garden Gulch member directly overlies the Wasatch formation. Northward along the outcrop the Garden Gulch member thins rapidly due to the reappearance and thickening of the Douglas Creek member—along upper Cathedral Creek it is about 300 feet thick, but along Lake Creek only 100 feet thick. To the north along the Cathedral Bluffs the member is poorly exposed, but the average thickness is probably about 200 feet. About 1,000 feet of beds identified as the Garden Gulch member is present in wells in the Piceance Creek gas field in the northeastern part of the area.

The Garden Gulch member is similar to the overlying Parachute Creek member, the principal difference being the lack of oil and carbonate, or a relatively low content, in most of the Garden Gulch in contrast to the high oil content and high carbonate content of much of the Parachute Creek member. However, the Garden Gulch member locally contains oil shale, some of which may prove to be of economic importance. In secs. 7 and 8, T. 7 S., R. 98 W., on the ridge between Roan and Kimball Creeks, shale samples from a zone at the base of the Garden Gulch member, collected and analyzed by Mr. W. O. Pray (written communication, 1951) of De Beque, assayed 14.6 gallons of oil per ton from a thickness of 6.3 feet. Scattered samples just above this zone showed a comparable oil content. These oil-bearing beds are black shale and limy claystone rich in ostracode remains and are different in appearance from most of the oil shales in the Green River formation.

Wells drilled in the Piceance Creek gas field have revealed significant amounts of oil shale in the Garden Gulch member (Duncan and Belser, 1950). Samples of rotary-drill cuttings from depths of 3,020 to 3,030 and from 3,040 to 3,050 feet in the General Petroleum well 5–31–G, from a zone about 10 to 30 feet below the top of the Garden Gulch member, assayed 32.4 and 33.2 gallons of oil per ton, respectively, and samples from a continuous sequence of 330 feet of the Garden Gulch had an average assay value of 15 gallons per ton. Other wells in the gas field contained smaller but still significant thicknesses of oil shale.

No core holes have been drilled through the Garden Gulch member, but two have reached the upper part. Five feet of shale from the bottom of the U.S. Bureau of Mines E core hole, sec. 2, T. 5 S., R. 95 W., averaged 5 gallons of oil per ton, and 12 feet of shale from the bottom of the Sun Oil Summers Cabin 3 well, sec. 2, T. 5 S., R. 97 W., averaged 9 gallons per ton.

At the head of Coal Creek in the northwestern part of T. 8 S., R. 100 W., the basal 50 feet of the Garden Gulch member is papery shale that is probably low-grade oil shale. Marlstone with low oil content was observed in a similar stratigraphic position along upper Roan Creek near the center of T. 6 S., R. 100 W. In the northern part of the Cathedral Bluffs and along the northern rim of the plateau as far east as the valley of Yellow Creek, the basal part of the Garden Gulch member consists of shale which probably contains oil. Along upper Big Spring Creek these beds have been burned at the outcrop.

ANVIL POINTS MEMBER

The Anvil Points member is found only in the eastern part of the area, from Parachute Creek valley north beyond the mouth of Piceance Creek a short distance. It crops out in benches and cliffs. In the northeastern part of the area the member apparently extends only a short distance back from the outcrop, for it is not present at the Piceance Creek gas field.

The Anvil Points member is the lateral equivalent of the Douglas Creek and Garden Gulch members and the lower part of the Parachute Creek member of the southwestern part of the area, and it is probably equivalent to the shore facies (Bradley, 1931) of the Green River formation in the Gray Hills just north of the mapped area.

On the north rim of the plateau it grades laterally into shale of the Garden Gulch member. It was called the lower sandy member by Duncan and Denson (1949) and was named the Anvil Points member (Donnell, 1953) from its excellent and complete exposure at Anvil Points in sec. 7, T. 6 S., R. 94 W. The type section was measured nearby in secs. 12 and 13, T. 6 S., R. 95 W., and is shown graphically in column 76 on plate 53.

The Anvil Points member is an extremely heterogeneous unit. At the type locality it contains approximately 30 percent gray shale, 25 percent gray shale and interbedded thin-bedded brown and gray sandstone, 20 percent massive brown and gray sandstone beds, and slightly less than 10 percent light-brown marlstone containing little or no oil. The remainder of the member consists of siltstone, algal limestone, and oolitic limestone. The Anvil Points member is 1,530 feet thick at the type locality. At upper Piceance Creek it reaches a maximum thickness of 1,870 feet.

The Anvil Points member interfingers with the upper part of the Wasatch formation, which it comformably overlies, and interfingers with the lower part of the Parachute Creek member of the Green River formation, by which it is conformably overlain.

The top of the Anvil Points member is at the base of a series of low-grade oil-shale beds and at the top of the uppermost sandstone bed in a sequence of barren marlstone alternating with gray and brown sandstone. To the north the upper part of the Anvil Points member interfingers with and is replaced by oil-shale beds in the lower part of the Parachute Creek member.

The base of the Anvil Points member is at the top of the uppermost red-shale bed, which has a minimum thickness of 10 feet. Along the east margin of the area the lowermost several hundred feet of the Anvil Points member interfingers with the red shale of the upper part of the Wasatch formation.

The base of the Anvil Points member interfingers with the Wasatch formation, which is regarded as early Eocene in age (Bradley, 1931, p. 8). The rest of the member interfingers with other members of the Green River formation that have been regarded as middle Eocene in age (Bradley, 1931, p. 9). A more precise determination of the age of the Anvil Points member has not been made. Several thin limestone beds, at or near the base of the member, contain nondiagnostic fresh-water gastropods and pelecypods.

PARACHUTE CREEK MEMBER

The Parachute Creek member contains the richest and thickest oil-shale beds in the Green River formation. The member was named by Bradley (1931, p. 11) for exposures in the vicinity of Parachute Creek, where the outcropping oil shale is richest and thickest. The member was recognized and mapped over the entire area of this report. It forms precipitous whitish cliffs near the crest of the plateau rim.

The member is composed almost entirely of shale and marlstone, most of which will yield oil when distilled. It is a little more than 1,000 feet thick in the type section (Bradley, 1931, p. 11) and has a maximum exposed thickness of 1,230 feet at Glover Point in sec. 22, T. 6 S., R. 96 W. In the subsurface it reaches greater thicknesses, however, for the General Petroleum well 5–31–G, sec. 31, T. 1 S., R. 96 W., penetrated a thickness of 1,700 feet. In the extreme northwestern part of the area, near the headwaters of Little Spring Creek, it has a minimum thickness of about 500 feet and contains very little oil.

Because of the potential economic importance of the oil shale, the Parachute Creek member has been studied in much greater detail than the other members of the Green River formation. As a result, the member has been subdivided, and several oil-shale units and thin marker beds have been identified and traced throughout the mapped area.

Bradley (1931, p. 11 and pl. 7) subdivided the Parachute Creek member at the type locality into a lower oil-shale group and an upper oil-shale group, separated by a thin sequence of oil-poor beds which he termed transitional beds. Duncan and Denson (1949) further subdivided Bradley's upper oil-shale group into the upper and middle oil-shale zones, separated by another thin sequence of marlstone containing little or no oil. The lower, middle, and upper oil-shale zones of Duncan and Denson are recognizable in parts of the southern part of the basin. However, in the subsurface toward the deepest part of the basin, the lower of the two barren units (the transitional beds of Bradley) becomes oil bearing and the lower and middle oil-shale zones coalesce. On the outcrop toward the margins of the basin the oil content of the lower and middle zones decreases so much that the zones are no longer separable. On the other hand, the upper oil-shale zone of Duncan and Denson and the upper of the two barren units of Duncan and Denson are recognizable at the outcrop and in subsurface samples throughout the basin, except for a small area in the extreme northwestern part.

The oil-shale zones are not shown separately on the geologic map (pl. 48). On the columnar sections (pls. 49–53) the classification of Duncan and Denson (1949) is followed, except that their middle and lower zones are undifferentiated. Past and present oil-shale-zone terminology is summarized in figure 72.

Lower and middle oil-shale zones

None of the oil-shale beds in the lower and middle oil-shale zones attains a richness comparable to the richest beds of the upper zone. On the outcrop, the thickness of oil shale in the lower and middle zones is also less than that in the upper zone. In the subsurface in the deepest part of the basin, however, much thicker sequences of shale which average 25 gallons of oil per ton are present at places in the combined lower and middle zones than are present in the upper zone. Rotary-drill cuttings from several wells in the northern part of the Piceance Creek basin indicate the presence of a continuous sequence more than 1,000 feet thick in the combined lower and middle zones that contains an average of 25 gallons of oil per ton, compared with only 220 feet in the upper zone that yields an average of 25 gallons of oil per ton. From this area of maximum development toward the margin of the basin, the combined lower and middle zones become thinner and their oil content decreases. Near the southwest edge of the area, in the northeast corner of T. 8 S., R. 100 W., the thickness of these zones is only 20 feet. In the extreme northwestern part of the area, northwest of Little Spring Creek, the combined lower and middle zones pinch out entirely between the Garden Gulch member and the upper oil-shale zone.

Evidently sedimentation conditions varied considerably from place to place during the time of deposition of the lower and middle oil-shale zones, for individual beds of rich oil shale cannot be traced for

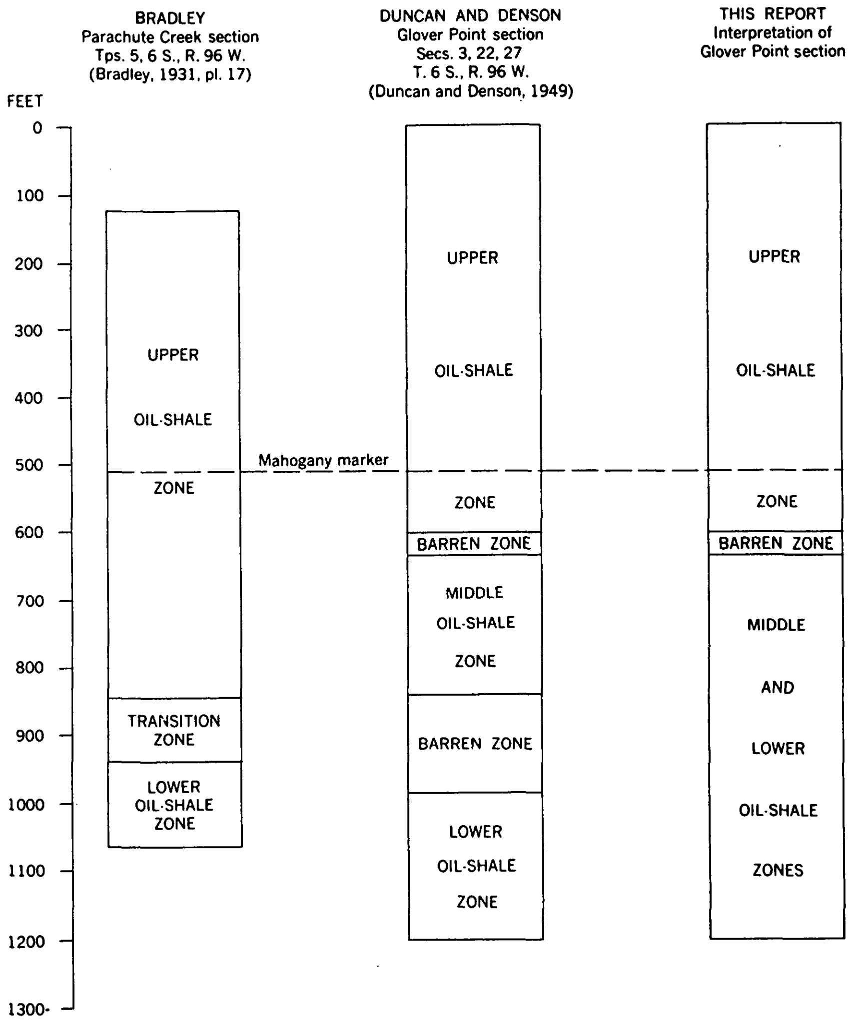


FIGURE 72.—Terminology of oil-shale zones, Piceance Creek basin, as used in this and in previous reports.

great distances along the outcrop as is possible with several beds in the upper zone.

Upper oil-shale zone

The upper oil-shale zone (pl. 57) is present throughout the area of this report and contains the richest and most important oil shale in the Green River sequence. The zone has a maximum known subsurface thickness of about 620 feet in the General Petroleum well 84–15–G, sec. 15, T. 2 S., R. 96 W. On the outcrop its thickness ranges from about 300 feet in the extreme northwestern part of the area to about 680 feet near Cow Ridge. In the extreme northwestern part of the area the oil shale contains much less oil than elsewhere, and the zone is difficult to distinguish from the Garden Gulch member on which it rests.

Certain oil-shale units within the upper oil-shale zone have been given separate designations because of their special importance. The basal part of the upper oil-shale zone is composed almost entirely of rich oil shale. The unit is called the Mahogany ledge at the outcrop and the Mahogany zone in the subsurface. The name Mahogany is derived from the fact that polished surfaces of much of the richest shale "simulate old mahogany in a remarkable manner" (Bradley, 1931, p. 23) and the term ledge from the fact that the unit generally weathers to a sheer cliff delimited above and below by reentrants.

The Mahogany ledge or zone varies considerably in thickness and oil content. It is thickest and richest in the deepest part of the basin. The General Petroleum well 22–3–G, sec. 3, T. 2 S., R. 96 W., penetrated a thickness of 110 feet of which 60 feet in continuous sequence showed an average oil content of 41.2 gallons per ton. Northwest of Rifle, the U.S. Bureau of Mines is mining a 73-foot section of the Mahogany ledge which has an average oil content of about 28 gallons per ton. Toward the margins of the mapped area the ledge or zone decreases in thickness and oil content, and in the extreme northwest corner of the area it cannot be distinguished from adjacent beds.

Within the Mahogany ledge or zone a persistent thin unit of exceedingly rich oil shale has been designated the Mahogany bed. Samples of parts of this bed have assayed as high as 79 gallons of oil per ton, and in the deeper parts of the basin the bed averages about 55 gallons per ton. Like the enclosing beds, it decreases in oil content toward the margins of the basin, but it is recognized throughout the region except for a strip about 10 miles long on the northwest margin of the area. The bed ranges in thickness from 3 feet along the margins of the basin to 10 feet in the deeper parts.

In the subsurface the Mahogany bed is massive and extremely tough. At many places on the outcrop the leaner laminae have weathered out, leaving thin sheets of rich oil shale, each separated from the next by a space about one-hundredth of an inch thick.

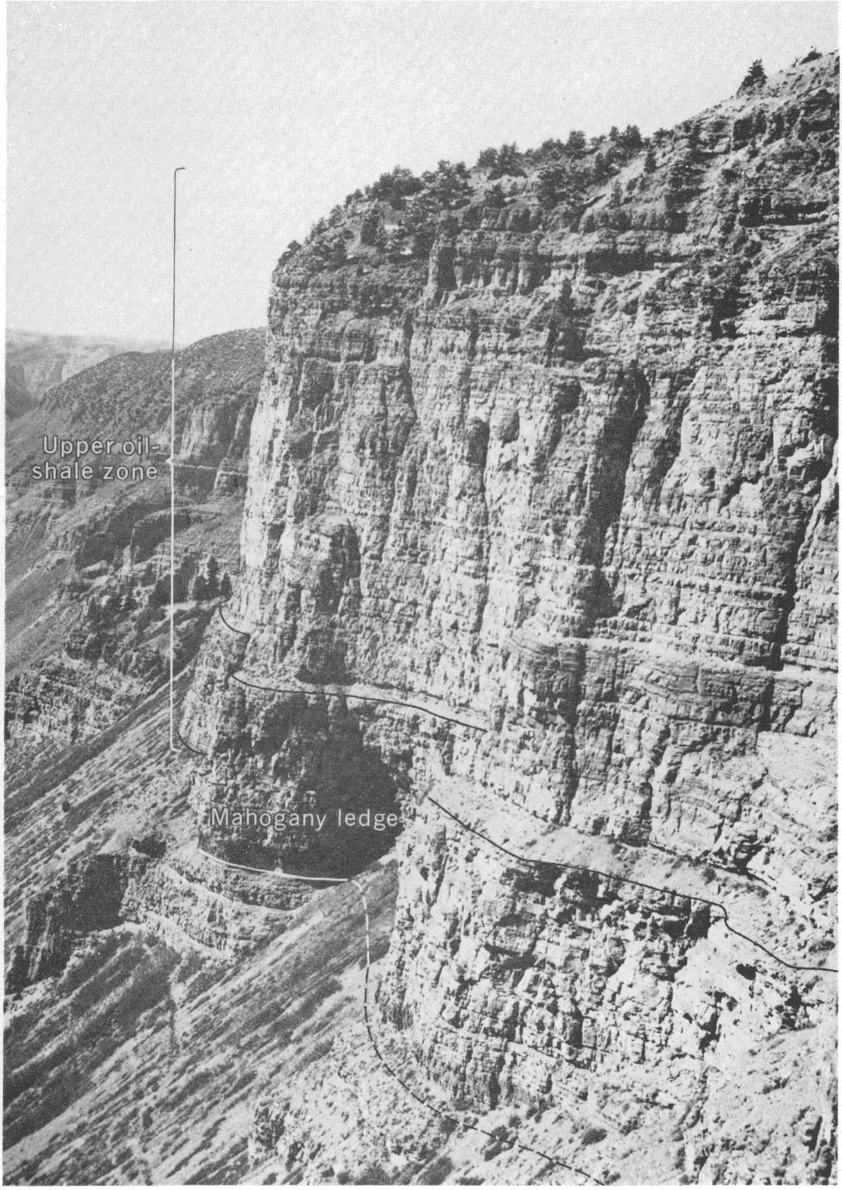
Because of its thinness and wide extent, the Mahogany bed is a useful key bed for stratigraphic reference and for structural mapping. Duncan and Denson (1949) identified and described several other key beds in the upper oil-shale zones. These beds have since been extensively used in other parts of the area and are enumerated below.

The lowermost of these key beds is tuff at or near the base of the Mahogany ledge. This tuff bed is distinctive in that its upper and lower contacts are extremely undulatory, and the thickness of the bed varies from a fraction of an inch to as much as 18 inches in a distance of several feet. Eight to ten feet above the undulating tuff is a blocky-weathering analcitized tuff bed generally about 2 inches thick. These two tuff beds can be followed along most of the south and west margins of the area, and they are present also in the eastern part of the Uinta Basin (Cashion and Brown, 1956).

An analcitized tuff bed that ranges from 3 to 6 inches in thickness is found from 3 to 14 feet above the top of the Mahogany bed and has been named the Mahogany marker. This bed is remarkably uniform in thickness and character throughout the southern three-quarters of the area. It was found in all sections examined along the south margin of the area, along the west margin as far north as Fletcher Gulch, and along the east margin as far north as upper Piceance Creek, and at scattered localities along the remainder of the north and east margins. Structure-contour maps drawn on this bed in the southern and western parts of the area have been published in other reports (Duncan and Denson, 1949; Waldron, Donnell, and Wright, 1951; Donnell, Cashion, and Brown, 1953) and the structure contours are shown on plate 3 of this report.

Another useful key bed is tuff that occurs 45 to 110 feet above the Mahogany marker. This bed is distinctive in that, in most places, it contains irregular stringers of marlstone that impart a wavy appearance to the lamination. This bed ranges in thickness from 10 inches along the Cathedral Bluffs to 5 feet in a road cut on upper Piceance Creek. It is nonresistant to weathering and hence is concealed by talus at many places. The bed is found throughout the southern part of the area and as far north as upper Piceance Creek on the east side of the area and Box Elder Creek on the west side of the area.

In the upper part of the Parachute Creek member a distinctive series of 3 thin rich oil-shale beds occurs within a stratigraphic interval of 15 feet. The uppermost bed is split by a thin, irregular stringer of analcitized tuff. The upper and lower oil-shale beds



UPPER OIL-SHALE ZONE, SHOWING MAHOGANY LEDGE

Exposure is on the East Fork of Parachute Creek. Photograph by D. C. Duncan.

weather to prominent ledges, and the middle bed forms a minor ledge. These beds have been identified with certainty throughout the southern part of the area. Elsewhere, poor exposure of the upper part of the member makes positive identification of these beds impossible.

About 30 feet above the uppermost of these 3 oil-shale beds and 280 to 345 feet above the Mahogany marker occurs the lowermost and most persistent of a series of marlstone beds characterized by numerous crystal cavities resulting from solution of crystals of gypsum and anhydrite. The lowermost bed is 20 to 317 feet below the top of the Parachute Creek member. The marlstone beds in the upper part of the member are especially useful in mapping since they are generally accessible, while the key beds lower in the section generally crop out in sheer cliffs.

EVACUATION CREEK MEMBER

The Evacuation Creek member, uppermost of the members of the Green River formation, was named by Bradley (1931, p. 14) for excellent exposures along Evacuation Creek in eastern Utah. The member forms the surface rock over most of the area of this report. It is a buff to light-brown rounded cap for the rim of the plateau that recedes somewhat from the sheer white cliffs of the underlying Parachute Creek member. Over the interior part of the plateau it forms rough hilly topography.

The base of the member was drawn at the base of the first sandstone or siltstone bed 10 feet or more in thickness that occurs above the uppermost sequence of key marlstone beds in the Parachute Creek member. Because the sandstone and siltstone beds in this part of the section are quite lenticular, the stratigraphic position of the boundary varies from place to place. At places in the northern part of the area the Evacuation Creek member rests nonconformably on truncated beds of the Parachute Creek member (see p. 861).

Because the top of the member in this area is the present erosion surface, its original maximum thickness cannot be determined. A thickness of 1,250 feet in the General Petroleum well 45X–29–G, sec. 29, T. 2 S., R. 95 W., is the greatest recorded thickness in the area.

The member is composed of barren marlstone, shale, siltstone, and sandstone. Sandstone becomes increasingly prominent toward the top of the member. Some beds of oil shale are present near the base in parts of the area.

The upper part of the Evacuation Creek member consists of thin beds of white to gray marlstone and siltstone and thick beds of massive brown medium- to coarse-grained sandstone. The sandier nature of the uppermost 400 feet led Bradley (1931, p. 19) to tentatively assign these beds to the Bridger formation. Attempts during the present investigation to establish a lithologic differentiation for mapping purposes were unsuccessful, and in the absence of fossil evidence the beds are herein included in the Evacuation Creek member.

The lithology of the Evacuation Creek member is quite variable, and beds or series of beds cannot be traced over any great distance. In the upper part of the member the only beds that can be followed for any distance along the outcrop are siltstone and marlstone that weather white on predominantly brown sandy slopes (pl. 58*A*). In the course of unsuccessful attempts to utilize such beds for structural mapping, it was found that they change in character and thickness and split into several beds, and that stratigraphic intervals between the beds vary considerably and irregularly in relatively short distances.

Lithologic variation in the lower part of the member is well illustrated by 3 core holes, all within a radius of 1½ miles in T. 4 S., R. 96 W., drilled by the Union Oil Co. of California in 1951. The beds of the upper oil-shale zone of the Parachute Creek member can be readily correlated in the cores, but the Evacuation Creek member differs radically from hole to hole. The easternmost hole, Buff, contained gray sandstone and siltstone through the entire 341 feet of the cored Evacuation Creek member. The westernmost hole, Rett, contained about 50 percent sandstone and siltstone and 50 percent low-grade marlstone with several beds of rich oil shale. The southernmost hole, Twig, contained mostly sandstone and siltstone with some low-grade marlstone and a few beds of fairly rich oil shale.

Three massive beds of rich oil shale ranging from 1 to 6 feet in thickness in the lower part of the Evacuation Creek member were found by Mr. W. O. Pray (written communication, 1951) on the divide between Roan and Kimball Creeks in the southwestern part of the area. Oil-shale beds of similar character and thickness have been found in approximately the same stratigraphic position at several places in the De Beque area, but no attempt at precise correlation has been made.

IGNEOUS ROCKS

A small erosional remnant of a basaltic flow is present on the summit of Mount Callahan, in sec. 16, T. 7 S., R. 96 W. The rock is composed principally of labradorite with a high percentage of mafic minerals. This undoubtedly was once part of the widespread flow now covering the greater part of Grand and Battlement Mesas to the south. Presumably, erosion by the Colorado River and its tributaries has isolated this remnant of a once extensive lava flow.

STRUCTURE

The area of this report comprises approximately the north one-half and deepest part of the Piceance Creek basin, a large structural downwarp. The basin is asymmetric, with very gently dipping limbs on the south and west and more steeply dipping limbs on the north and east (pl. 48). In the Green River formation the dips range from as low as 0.5° on the south margin to as great as 27° on the north rim. This asymmetry is much more pronounced in the older rocks; the Mesaverde rocks along the Grand Hogback are locally vertical or even overturned.

Within the mapped area, the axis of the basin at the surface roughly parallels the north and east margins of the area at a position about 10 to 15 miles from those margins. Inasmuch as the Wasatch formation and the Mesaverde group thicken markedly east across the area, the position of the basin axis at progressively deeper horizons undoubtedly shifts more and more toward the east margin. In the northeastern part of the area a syncline with a sinuous axis branches north from the main basin and forms a small subsidiary basin north of the White River.

The Piceance Creek basin is bordered on the east and northeast by the White River uplift and the Axial Basin anticline. On the northwest the axis of the basin is expressed as a syncline between two great anticlines associated with the Uinta uplift, the Blue Mountain and Rangely anticlines. Extending southward from the Rangely anticline is the Douglas Creek arch, a broad gentle upwarp which bounds the Piceance Creek basin on the west. On the southwest the basin is bordered by the Uncompahgre uplift, an ancient feature of low topographic but high structural relief. (See fig. 73.)

Numerous small subparallel northwest-trending folds were observed in the Green River in the part of the basin covered by this report. The most prominent of these folds is the Piceance Creek dome in the northeastern part of the area. It is about 10 miles long and has a structural closure in the surface rock of 200 to 250 feet (Kramer, 1939). Development drilling following the discovery of natural gas in the basal Green River formation has shown that the structure in the basal Green River does not coincide with that in the surface rocks. The available subsurface data indicate the presence of a northwest-trending anticline with its axis offset to the southwest from the surface axis.

A syncline which generally plunges northwest, but has a small area of closure near the forks of Parachute Creek, has been mapped (Duncan and Denson, 1949; Waldron, Donnell, and Wright, 1951) in the southern part of the area. North of this syncline a west-plunging anticlinal nose is present in the northern part of Naval Oil-Shale Reserves Nos. 1 and 3. In the area between Parachute and Roan Creeks, the northwest-plunging Crystal Creek anticlinal nose is paralleled for a few miles on the southeast by the Clear Creek syncline, which

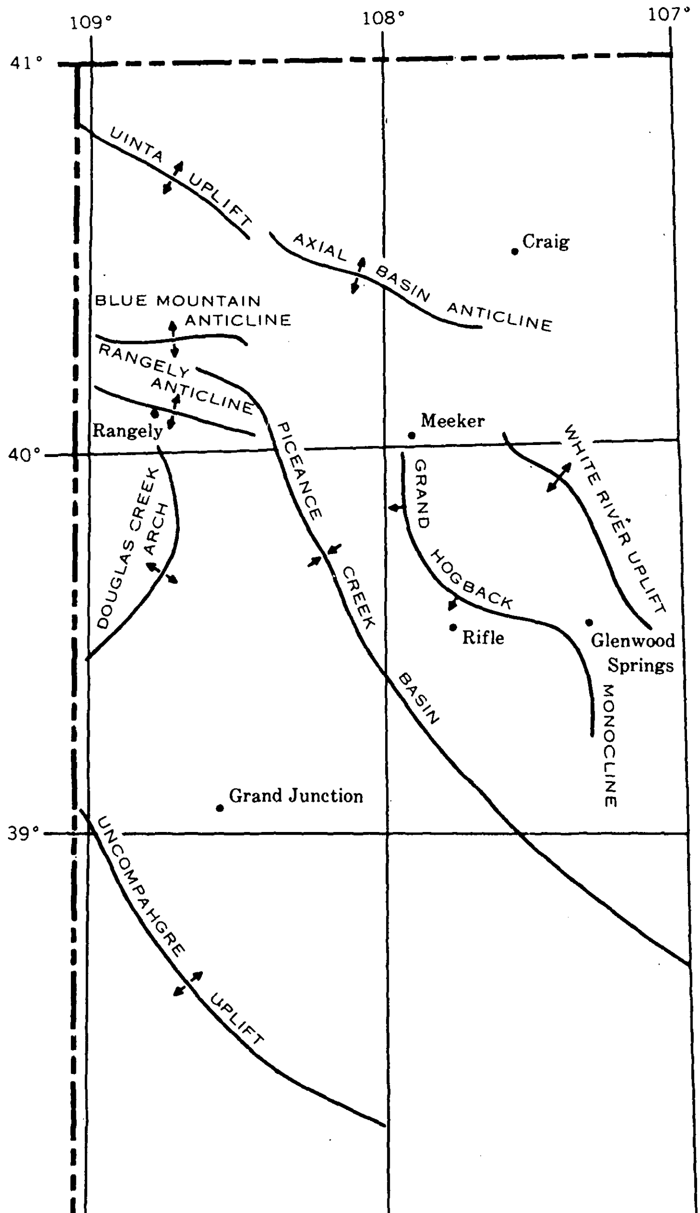
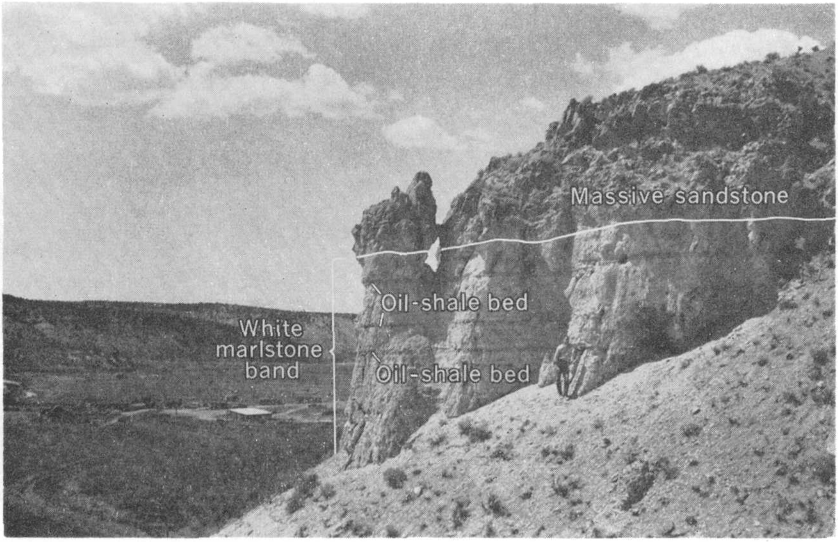
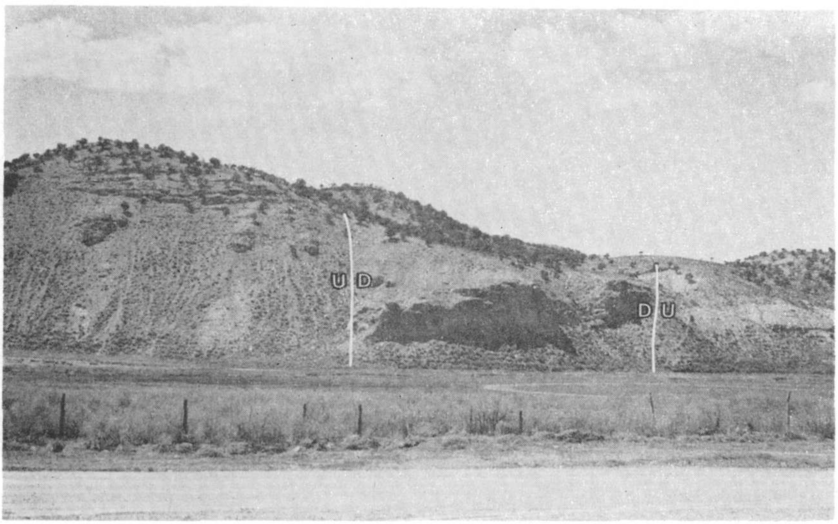


FIGURE 73.—Structural features in northwestern Colorado.



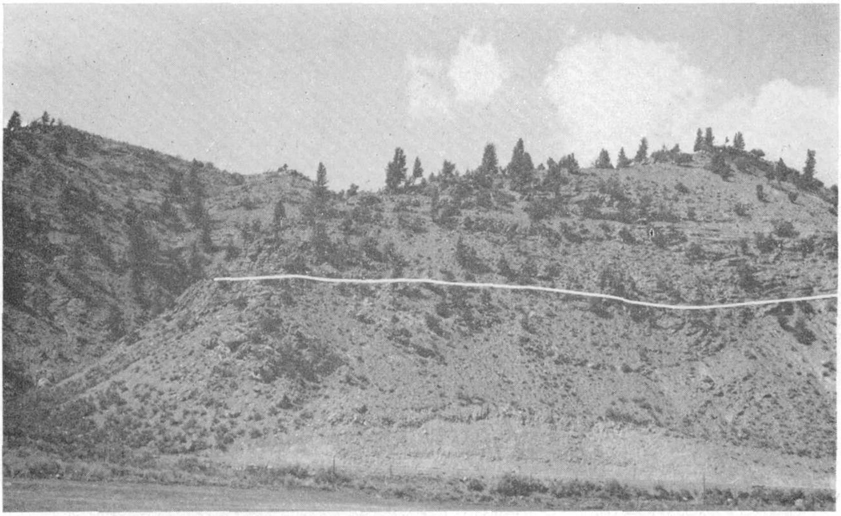
A. BARREN MARLSTONE, EVACUATION CREEK MEMBER, GREEN RIVER FORMATION

Exposure on Piceance Creek, about 1 mile south of Black Sulphur Creek.



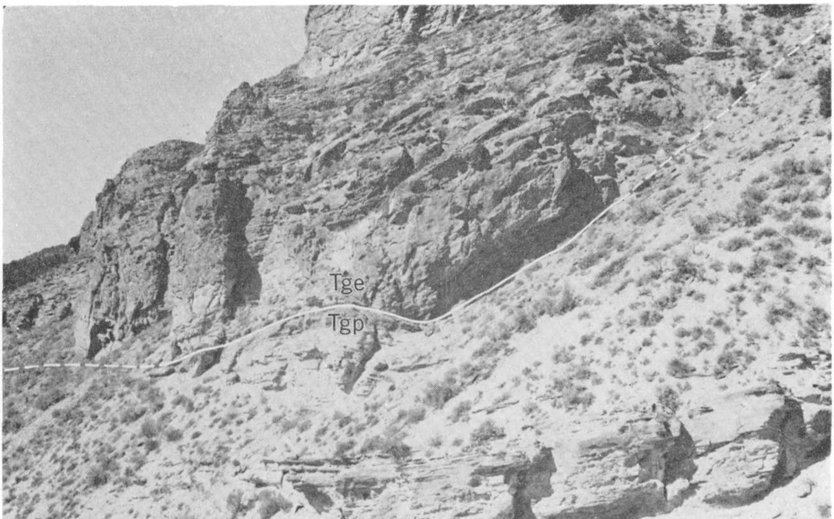
B. GRABEN ON THE WEST SIDE OF PICEANCE CREEK

Sandstone in the middle of the picture is in the dropped block. Exposure is about one-half mile south of Ryans Gulch.



A. UNCONFORMITY WITHIN EVACUATION CREEK MEMBER, GREEN RIVER FORMATION

Flat-lying beds of sandstone overlie truncated beds of sandstone and marlstone in a syncline. Exposure on Piceance Creek, about 2 miles west of junction of Piceance and Fourteenmile Creeks.



B. UNCONFORMITY WITHIN THE GREEN RIVER FORMATION

Sandstone of the Evacuation Creek member (*Tge*) overlies the truncated Mahogany bed of the Parachute Creek member (*Tgp*). Exposure near mouth of Greasewood Creek, sec. 17, T. 2 N., R. 98 W.

has a closure of a little over 200 feet (Waldron, Donnell, and Wright, 1951). On the west side of the area near the headwaters of Cathedral and Black Sulphur Creeks a pronounced southeast-plunging anticlinal nose is generally alined with the Crystal Creek anticlinal nose but separated from it by a low saddle. A similar southeast-plunging anticlinal nose is present farther north in the vicinity of Box Elder Creek and Corral Gulch. Another nose plunges southeast at the head of Barcus Gulch.

Woodruff (1913, p. 60–61) has described an anticlinal fold in beds of the Wasatch formation that extends west about 8 miles from near the town of De Beque.

Several normal faults, most of them with a displacement of less than 50 feet, were observed in the northeastern part of the area on and just to the west of the Piceance Creek dome (pl. 58*B*). These faults, like the folds, trend northwest. Most of the fault zones are coated or filled with calcium carbonate, and at one place along Black Sulphur Creek in the SW¼ sec. 27, T. 2 S., R. 98 W., the calcium carbonate includes many stringers of a solid hydrocarbon resembling gilsonite. Winchester (1923, p. 40) reported the occurrence of a yellowish-brown hydrocarbon filling a fracture zone 2 or 3 feet wide in Jessup Gulch, a tributary of Piceance Creek.

A well-defined system of northwest- and northeast-trending joints are present in the Green River strata. In the west-central part of the area, a partial adjustment of streams to this joint system has resulted in a trellislike drainage pattern.

Some folding of the older members of the Green River formation may have occurred before and during the deposition of the Evacuation Creek member and therefore may not be reflected in the surface rocks in the interior of the basin. In the area near the junction of Schutte Gulch and Piceance Creek (northeastern part of T. 4 S., R. 95 W., and southeastern part of T. 3 S., R. 95 W.), flat-lying sandstone beds rest on steeply dipping oil shale of the Parachute Creek member in several places. Duncan and Belser (1950) noted a structural discordance within the Evacuation Creek member at a locality about 2 miles west of the junction of Piceance and Fourteenmile Creeks (pl. 59*A*). Near the mouth of Yellow Creek, in the extreme northern part of the area, evidence of very notable truncation of the Parachute Creek member before deposition of the Evacuation Creek member is present. East of the mouth of Yellow Creek a massive yellow sandstone unit at the base of the Evacuation Creek member lies about 450 feet above the Mahogany bed, whereas 1 mile to the west, north of the mouth of Greasewood Gulch, the same sandstone rests on beds of the Parachute Creek member that are older than the Mahogany bed

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(pl. 59*B*). The full nature and extent of these truncated structural features that were formed during the deposition of the upper part of the Green River formation were not determined in the present investigation.

GEOLOGIC HISTORY

The present Piceance Creek structural basin was a basin of deposition during the Eocene epoch. This is shown by the fact that the Eocene sedimentary rocks are thickest near the axis, and that they thin toward the basin margins. When this depositional basin first came into being has not been determined. At least one of its bordering uplifts, the Douglas Creek arch on the west, must have been present in Late Cretaceous time, for the rocks of the Mesaverde group thin westward toward the arch. The coarse detritus of the Paleocene(?) Ohio Creek conglomerate, which is well developed on the south and east sides of the basin, may reflect the uplift of the marginal features in the south and east that completed the formation of the depositional basin. The basin had certainly taken form by early Eocene time, for the Wasatch formation thickens toward the center of the basin.

The physical characteristics and fossil content of the rocks from the uppermost Mesaverde group through the Wasatch formation indicate that the bulk of the sediments was deposited by aggrading streams. At some time late in the early Eocene the outlet of this stream system was blocked, presumably by crustal upwarp, and a great lake was formed in which the sediments of the Green River formation were deposited. The Douglas Creek arch was inundated, for the Green River strata in the western part of the Piceance Creek basin are virtually identical with those of the eastern Uinta Basin and show no evidence of an intervening land area. This great ancient lake of Eocene age in what is now eastern Utah and western Colorado has been named Uinta Lake (Bradley, 1929, p. 88). The physiographic, hydrographic, climatic, and biologic conditions that prevailed during the deposition of the Green River formation have been discussed at length by Bradley (1929, 1931, 1948).

Sediment accumulating near the shores of the ancient lake included much sand; sediment accumulating in the parts of the lake remote from the shoreline consisted of clay and marl rich in organic matter that formed the present oil shale. The geographic and stratigraphic distribution of these lithologic components sheds light on the history of the lake. In the earliest stages of the lake, the northwestern and southwestern parts of the mapped area must have been most remote from the shores, for there shale referred to the Garden Gulch member rests directly on the Wasatch formation. At the same time, sandy sediments of the Douglas Creek member were accumulating in the southern and central parts of the area, and similar rocks of the lower part of the Anvil Points member were accumulating in the eastern part of the area. Then the lake must have expanded considerably, for deposition of fine-grained sediment now constituting the Garden Gulch member and the lowermost part of the Parachute Creek member spread over most of the area. A great thickness of oil shale accumulated in the deeper parts of the basin. The east margin of the mapped area was still nearshore, as shown by the sandiness of the upper part of the Anvil Points member. The rocks of the upper part of the Parachute Creek member record a further expansion of the lake, which presumably reached its maximum extent at the time of deposition of the Mahogany bed. At that time the entire area of this report must have been remote from the margins of the lake, except for the extreme northwestern part where the Mahogany bed is not present and the Parachute Creek member is no finer grained than the older sediments. The rocks overlying the Mahogany bed record a fluctuating but overall gradual contraction of the lake and the beginning of a return to fluvial deposition as indicated by coarse-grained channel sandstone in the upper part of the Evacuation Creek member. Here the sedimentary record ends. Whether fluvial deposition continued into the Oligocene epoch, as it did in the Uinta Basin to the west, is not known; if deposition did continue the deposits have since been removed by erosion.

Structural development during the Eocene epoch consisted of continuous downwarping of the basin, as indicated by the great thickness of sedimentary rocks and the thickening of the sedimentary rocks toward the center of the basin. The earliest evidence of local folding is the structural discordance in places of the basal beds of the Evacuation Creek member (p. 861), but the extent and magnitude of these disturbances are not known. The earth movements which resulted in most of the present structural relief of the basin took place after the deposition of the Green River formation, for the Green River strata are turned up rather sharply where they approach the bordering uplifts. The faults and minor folds in the area probably were formed at the same time.

ECONOMIC GEOLOGY

OIL SHALE

PHYSICAL CHARACTERISTICS

Marlstone or shale that yields an appreciable amount of oil upon distillation is classed as oil shale. Rich oil shale has a high organic content which imparts a waxy luster and a dark-brown, reddish-brown or nearly black color to the rock. The high organic content enables the rock to resist erosion better, and rich shale beds weather to ledges, whereas lean and barren marlstone weathers to groooves or slopes. The color of weathered surfaces of the rock ranges from white to gray for barren or lean oil shale and through shades of brown and cream to shades of light to dark blue for the richest oil shale. The rich oil-shale beds are extremely tough and usually break across the bedding plane with a conchoidal fracture, whereas lean and barren marlstone is extremely brittle and breaks along bedding planes. Thin edges of fragments of oil shale that yields more than 35 gallons of oil per ton burn with a yellow smoky flame for a short period of time. The specific gravity of the oil shale and marlstone is in inverse proportion to the oil content. Oil shale yielding 75 gallons of oil per ton has an average specific gravity of about 1.63, whereas that of marlstone containing virtually no organic matter is about 2.71.

The oil shale and marlstone are composed of pairs of thin laminae called varves (Bradley, 1929, p. 95). One of the pair is rich in organic material, the other has a high mineral content. The two layers are sharply defined in moderately rich oil shale, but in extremely rich oil shale the organically rich layer is almost lacking in mineral matter and the mineral layer has a quite high percentage of organic material; the reverse is true with nearly barren marlstone; therefore, lamination in either rich oil shale or nearly barren marlstone is indistinct.

COMPOSITION OF THE OIL SHALE AND MARLSTONE

Studies by Bradley (1931, p. 29–37) of the inorganic components of oil shale have shown that the syngenetic minerals, dolomite and calcite average about 36.5 and 16.5 percent by weight, respectively. Analcite is commonly present and may constitute as much as 16 percent by weight. Pyrite occurs in disseminated form, principally throughout the rich oil shale. It formed through the reaction of H_2S, released in the putrefaction of organic oozes, with iron salts dissolved in the lake water. Clay minerals, notably illite, are dominant among the clastic constituents of the marlstone (Stanfield and others, 1951). Some of the beds consist of as much as 21 percent clay materials. Other clastic minerals such as quartz, sanidine, feldspar, muscovite, zircon, and apatite are found in minor amounts. The minor clastic minerals are not sorted, and are associated with volcanic minerals and volcanic glass, which indicates that all or most of the clastic minerals other than clay minerals had a volcanic origin.

Salt cavities are common in the Parachute Creek member and range in length from a few millimeters to 5 feet. They are conspicuous along

Parachute Creek and especially well developed in the Mahogany ledge. Along the outcrop the salt has in most places been leached out, and in some places it has been replaced by a solid hydrocarbon that resembles gilsonite. In many core-drill holes and in the U.S. Bureau of Mines underground quarry west of Rifle, Colo., the original salt, the rare water-soluble sodium bicarbonate mineral nahcolite (Ertl, 1947; Glass, 1947) is present.

Small granules of calcite and slightly larger particles of chert are found between the laminæ of the oil shale. These were formed at the time the oil shale was still an organic ooze, for the bedding planes of the oil shale bend around the particles.

The organic matter in the oil shale is lemon yellow to reddish brown, and most of it appears to be structureless even under high magnification. However, some of it contains many remains of microorganisms that are visible under high magnification. These include algæ, protozoa, insects, and parts of higher plants—spores, pollen grains, and minute pieces of tissue (Bradley, 1931, p. 39).

HISTORY OF DEVELOPMENT

It has been estimated that there is over a million million tons of workable oil shale in the world (Prien, 1950, 1951). These deposits occur in almost every major country in the world. The first attempt to produce oil from shale was in 1684 when English Patent No. 330 was issued for the production of "oyle from a kind of stone" (Prien, 1950). The first commercial production of oil from oil shale was obtained in France in 1838. After this, oil-shale industries began in Scotland, Australia, Canada, New Zealand, Switzerland, Sweden, Estonia, England, Ireland, Wales, Manchuria, and Russia. In 1857 oil-shale activities began in the United States with the distillation of 300 gallons a day of oil from Devonian shale in an Ohio River valley plant. Interest in the oil shale of the Western United States began in 1916, and small commercial production continued until 1927.

The early activities in the mapped area were generally confined to the area north of De Beque on Dry Fork, Kimball, Conn, and Roan Creeks, although the Columbia Oil Shale Co. obtained land and set up installations on the east fork of Parachute Creek. The Grand Valley Oil and Shale Co. laid a foundation for a retort in Starkey Gulch, 6 miles northwest of Grand Valley; the March Oil Shale Co. installed a 4,000-foot surface tramway in Wheeler Gulch, 5 miles north of Grand Valley; and the Continental Oil-Shale Mining and Refining Co. began the operation of a retort on upper Piceance Creek just west of Rio Blanco. Many assessment pits were dug throughout the southern part of the area, and a few other pits were dug at scattered localities in the rest of the basin.

In 1925 the U.S. Bureau of Mines constructed a small experimental plant at Rulison, a few miles west of Rifle, Colo. (Gavin and Desmond, 1930). This plant was established for the purpose of applying the fundamental principles that had been worked out in the laboratory to the retorting and refining of oil shale on a semicommercial scale. The plant was in operation from September 1926 to June 30, 1927.

A rather complete history of the oil companies' oil-shale activities beginning with the initial purchase of oil-shale land in 1921 by the Union Oil Co. of California and ending with a summation of the oil-shale holdings of the major oil companies as of January 1956 is presented by Prien and Savage (1956, p. 17J–18J, fig. 1 and table 1).

The early attempts to establish an oil-shale industry in this area failed because shale oil could not compete with liquid crude oil. Interest subsided for many years, until World War II.

Although crude-oil production kept pace with consumption in the early years of World War II, increasing demands of the military and the cutting off of foreign sources of crude oil caused the Federal Government to seek supplementary domestic sources of liquid fuel. From 1945 to 1955 the U.S. Bureau of Mines operated an experimental oil-shale mine and retorting plant northwest of Rifle, Colo., to evaluate the potential of Naval Oil-Shale Reserves Nos. 1 and 3 and to aid future establishment of a commercial oil-shale industry.

About the same time that the Bureau of Mines began its operations near Rifle, some major oil companies started exploratory core-drilling programs to determine the value and extent of their oil-shale holdings. In 1948 the Union Oil Co. of California drilled 4 core holes near the forks of Parachute Creek between the east side of Parachute Creek and the western boundary of Naval Oil-Shale Reserves Nos. 1 and 3 in Tps. 5 and 6 S., R. 95 W., and in the summer of 1951 the same company drilled 4 more core holes in T. 4 S., R. 96 W. The Sun Oil Co. drilled 3 core holes in the area between the West Fork of Parachute Creek and Clear Creek in T. 5 S., R. 97 W. The Pacific Oil Co. drilled 6 core holes along both sides of Clear Creek in Tps. 5 and 6 S., Rs. 98 and 99 W. In the summer of 1951 Denver University drilled the Cascade 1 core hole in sec. 10, T. 7 S., R. 98 W., and in the fall of 1951 the Weber Oil Co. drilled 2 core holes—1 at the head of Ryan Gulch on the east slope of the Cathedral Bluffs in sec. 28, T. 3 S., R. 99 W., and 1 at Black Sulphur Creek in sec. 10, T. 4 S., R. 99 W. The U.S. Bureau of Mines has carried on an active exploratory coring program, and from 1945 to 1955 drilled 9 core holes in Naval Oil-Shale Reserves Nos. 1 and 3. The location of core holes drilled in the area is shown on plate 48.

Although no commercial production is now obtained from the oil shale, these core-drilling programs reflect an active interest in the oil shale of the area. Several freight-car loads of shale mined by the Bureau of Mines have been sent to the research laboratories of the Standard Oil Co. of California and the Union Oil Co. of California. There the shale is put through the companies' test retorts and the oil that is obtained is refined and tested for quality and quantity of lighter and heavier fractions.

RESOURCES

Although in the latter part of the last century the beds of the Green River formation were known to contain hydrocarbons in considerable quantity (Peale, 1876; and Eldridge, 1901), no attempt was made until recently to determine the total amount of petroleum contained in these beds. Winchester (1928, p. 13), from the results of his fieldwork between 1913 and 1918, estimated that the oil shales of Colorado contained 79,625,998,000 barrels of oil (47,625,598,000 barrels recoverable); Winchester also measured many stratigraphic sections and collected between 300 and 400 scattered samples of oil shale for assay. Little additional information became available until the resumption of geologic studies by the U.S. Geological Survey and establishment of the U.S. Bureau of Mines experimental plant near Rifle, Colo., in 1945. Between 1945 and 1949 the U.S. Bureau of Mines and oil companies drilled 25 diamond-drill holes and 4 gas wells. Belser (1951, p. 8–9) calculated from the assays of core samples and rotary-drill cuttings that an area of 1,000 square miles underlain by beds yielding an average of 25 gallons of oil per ton contains approximately 125,000 million barrels of oil, and that the same area underlain by a greater thickness of shale yielding 15 gallons of oil per ton contains approximately 500,000 million barrels of oil. The Geological Survey estimated in 1951 that parts of the oil-shale deposits in Colorado that yield an average of 15 or more gallons of oil per ton have a potential yield of at least 750,000 million barrels (U.S. Congress, Senate Committee on Interior and Insular Affairs, 1951, p. 169–171). These figures did not take into account any losses in mining or retorting the oil shale.

A summary of estimates of tonnage and oil content as determined in the present survey has recently been issued (Donnell, 1957a), and these estimates are included in this report (pl. 54 and tables 2–5). New information from extensive exploration in the northern part of the area has indicated that zones of shale below the Mahogany ledge that contain 25 and 30 gallons of oil per ton are much thicker and more extensive than suspected when those estimates were made (Donnell, 1957b). Thus the earlier estimates (Donnell, 1957a, p. 265 and 270) of the total quantity of shale of these grades in the lower zones were much too conservative (see p. 872).

Principal sample localities from which data were obtained for the present reserves estimates are shown on plate 48 and are listed in table 1 (p. 877). Assays of the oil content of individual samples at most of these localities are tabulated and shown graphically in recent publications of the U.S. Bureau of Mines (Stanfield and others, 1954, p. 25–95; 1957, p. 9–132).

Data available at present are adequate for preparing a preliminary regional-thickness map of shale yielding 15 gallons of oil per ton for the entire area and for the entire stratigraphic range of occurrence (pl. 54*D*). For shale yielding 25 and 30 gallons, the data permit preparation of regional-thickness maps only for such shale in the principal oil-shale zone (pl. 54*B* and *C*). Information on the thickness of shale yielding 45 gallons per ton is limited to the southern part of the area (pl. 54*A*).

CRITERIA USED IN MAKING ESTIMATES OF TONNAGE AND OIL CONTENT OF OIL SHALE

To compute the tonnage and oil content of the oil shale, the oil-shale sequence was divided into several units on the basis of average oil yield, and reserves were computed separately for shale yielding 15, 25, 30, and 45 gallons of oil per ton. A minimum thickness of 5 feet was used for shale averaging 45 gallons per ton, and a minimum thickness of 15 feet was used for the other grades.

The minimum thickness and grade of oil shale used in compiling this report in part correspond approximately to the minimum thickness and grade of oil shale exploited on a sustained basis in other parts of the world. In Estonia, for example, oil shale (kukersite) in beds ranging from about 5 to 8 feet in thickness and yielding 45 to 55 gallons of oil per ton have been mined and processed for oil since about 1921 (Lutz, 1938; Guthrie and Klosky, 1951). Oil shale yielding as little as 15 gallons of oil per ton has been mined on large scale and processed in other places, such as in Sweden (Cadman, 1948; Guthrie and Klosky, 1951).

Thus far, oil shale has not been developed on a large commercial scale in this country; therefore, it is not possible to predict with assurance what average grade will eventually prove most suitable, or what the minimum minable thickness will be. Results of research in processing oil shale by the U.S. Bureau of Mines at a pilot plant near Rifle indicate an optimum grade ranging between 25 and 33 gallons of oil per ton, and the underground mining methods developed by the Bureau of Mines require a minimum thickness of 25 feet of shale, which is the minimum operating room required by the equipment used. Continued advancement in the technology of mining and processing oil shale may alter these limits; consequently, a wider range in grade and thickness was used in this report. Moreover, no attempt is made to predict how much oil will be lost in mining and processing the oil shale, and no allowance is made for such losses in the estimates of tonnage and oil content of the shale.

METHODS USED IN COMPUTING ESTIMATES OF TONNAGE AND OIL CONTENT OF OIL SHALE

For each locality where there was information on the oil content of the shale sequence, the data were studied to determine the maximum thickness of shale units in continuous sequence that have an average oil content of 15, 25, 30, and 45 gallons per ton, respectively. Thickness data so obtained were then used to construct a series of thickness maps (pl. 54) from which the average thickness of each grade of oil shale was estimated for each township. The volume of oil shale of given grade in each township was then computed and converted to tons by using the estimated specific gravity of the shale.

The basic information on oil content generally consists of individual assays of a series of samples taken in vertical sequence; the samples may vary considerably both in thickness of strata represented and in oil content. Specific-gravity determinations are not made in routine assays, but it has been established that lean oil shale is denser than rich oil shale (Belser, 1951, p. 5). In combining the assay data for a series of individual samples to determine the average assay value of the total thickness, the values of the individual samples were weighted according to the thickness of strata represented but were not weighted according to specific gravity. Where assays of samples of varying richness are combined, failure to weight the sample data according to specific gravity results in an average assay value that is slightly higher than actual. However, this error is generally small, particularly where the range in assay value is not large, which is generally true. As other uncontrolled or unappraisable factors involved in the reserve estimates represent greater theoretical sources of error, and as actual specific-gravity determinations on the individual samples were not made, weighting of the sample data according to estimated density was considered unwarranted for this inventory. Although various assay methods were used to determine the oil content of the shale, most of the samples were analyzed by the modified Fischer method as described by Stanfield and others (1951), who indicate that the yields and characteristics of the products by this method may not be comparable to those obtained under different retorting conditions or from commercial-size units. The relative oil yields and data on products obtained from some larger experimental retorts are described by Guthrie (1955).

Estimates of tonnage and oil content of the oil shale have been broken down into two categories, indicated and inferred, that show the relative reliability of the estimates. Tonnage and oil content in the indicated category are considered more accurate than the inferred category. In most places, areas for which analyses are of cores spaced less than 6 miles apart contain indicated potential reserves. A few areas where the cores are more than 6 miles apart—but where the general increase or decrease in organic content is indicated to be uniform by many nearby cores—are also regarded as areas of indicated potential reserves. Reserves within approximately 2 miles of an isolated sampled locality are regarded as indicated. If there are several sampled localities roughly in line, the outer limits of indicated reserves are 2 miles from this line. Reserves within 2 miles of a well or group of wells whose rotary-drill cuttings have been analyzed are considered indicated for shale averaging 15 gallons of oil per ton. Sample intervals in rotary-drill holes are generally 10, 20, or 25 feet and are considered too great for even the moderate reliability desired to classify indicated reserves of the shale that yields 25 and 30 gallons of oil per ton and are considered inadequate for estimating potential reserves of the thin shale unit that contains 45 gallons per ton.

Oil shales at the surface are exposed to weathering and may lose as much as 50 percent of their oil (Winchester, 1917, p. 162–163, pl. 14). Also, lean oil shale breaks much more easily than rich oil shale, and, unless great care is taken to cut a uniform channel while sampling, a representative sample will not be obtained. Hence, data obtained through surface sampling are not generally used in this report to delineate areas of indicated reserves. However, in places where the oil shale showed little weathering and a representative sample was obtained, the analytical data were used in the computation of indicated reserves.

An experienced investigator can estimate with moderate accuracy the oil content of oil shale from its physical characteristics. Estimates tend to be conservative, and they have not been used in the calculation of indicated reserves; however, they were used in estimating the oil content in areas of inferred reserves.

SUMMARY OF POTENTIAL RESERVES

The following estimates of tonnage and oil content of the oil-shale deposits include the total amount of oil shale in place and total potential oil yield, assuming that all the oil could be extracted from the deposit. Recoverable oil from the deposits will doubtlessly be much less than the total potential yield of the deposits because of losses in mining and processing and other, unappraised, cutoff limits of grade, depth, or distance from outcrop of a selected shale unit that may be exploited in the future. No attempt is made in this report to estimate the amount of oil recoverable from the deposits.

Estimated tonnage and oil content of shale in that part of the Mahogany zone that contains an average of 45 gallons of oil per ton in a continuous sequence 5 feet or more thick are shown in table 2. Distribution and thickness of the part of the unit for which estimates were made are shown on plate 54*A*. Approximately 261 square miles of the area is underlain by indicated reserves of about 6,360 million tons of such shale with an oil content of about 6,800 million barrels. In addition, about 27 square miles is underlain by inferred reserves of about 655 million tons of oil shale with an oil content of about 700 million barrels.

Estimates of tonnage and oil content of shale yielding 45 gallons of oil per ton are made only for the south half of the area (pl. 54*A*), where numerous analyses of both cores and surface samples indicate fairly well the thickness of oil shale. Except for 3 core holes in the southern part of T. 3 S., R 99 W., and 2 core holes in T. 1 S., R. 100 W., no oil-shale samples from north of the north boundary of T. 4 S. supply a basis for estimating the thickness of shale that yields an average of 45 gallons of oil per ton. Analysis of cuttings from one well in the Piceance Creek gas field suggests the presence of shale that yields 45 gallons of oil per ton: The General Petroleum well 5–31–G, sec. 31, T. 1 S., R. 96 W., yielded one 10-foot sample in the Mahogany zone that assayed 43.9 gallons of oil per ton.

The thickest known sequence (31 feet) of shale that yields 45 gallons of oil per ton in the area was obtained from the U.S. Bureau of Mines E core hole, sec. 2, T. 5 S., R. 95 W.

Estimates of tonnage and oil content of that part of the Mahogany zone and adjacent beds that yields an average of 30 gallons of oil per ton in a continuous sequence 15 feet or more thick are shown in table 3, and the thickness and distribution are shown on plate 54*B*. The unit includes the oil shale that yields 45 gallons of oil per ton (table 2). An area of approximately 447 square miles contains indicated reserves of about 52,000 million tons of shale with a potential yield of about 37,000 million barrels of oil. In addition, approximately 683 square miles contains inferred reserves of about 76,000 million tons of shale with a potential yield of about 54,000 million barrels of oil.

The General Petroleum well 22–3–G, in sec. 3, T. 2 S., R. 96 W., contains 130 feet of shale in a continuous sequence in the Mahogany zone that yields an average of 30 gallons of oil per ton.

Assays of rotary-drill cuttings of wells drilled for oil and gas indicate that oil-shale zones yielding 30 gallons of oil per ton occur below the Mahogany zone. These zones in places are more than 500 feet thick. Near the junction of Black Sulphur Creek and Piceance Creek the Mahogany zone and the lower zones coalesce, but at places they are separated by as much as 1,500 feet. The lower zones underlie an area of about 400 square miles in the northern part of the Piceance Creek basin in Tps. 1 N.–4 S., Rs. 95–99 W. (Donnell, 1957b, p. 162, fig. 1). New detailed estimates have not been made, but it is apparent that there is at least 101,000 million tons of shale that yields 30 gallons of oil per ton, a total of about 72,000 million barrels of oil, in the lower zones. These totals are in addition to those estimated for oil shale in the Mahogany ledge and adjacent beds as shown in table 3.

Estimated tonnage and oil content of that part of the Mahogany zone and adjacent beds that yield an average of 25 gallons of oil per ton in a continuous sequence 15 feet or more thick are shown in table 4, and the distribution and thickness of the unit are shown on plate 54*C*. The unit includes the shale that yields 30 gallons of oil per ton (table 3). Indicated reserves of about 93,000 million tons of shale that contains about 55,000 million barrels of oil underlie an area of 452 square miles. Inferred reserves totaling about 167,000 million tons of shale that contains about 100,000 million barrels of oil underlie an additional 751 square miles. The thickest sequence of shale that yields 25 gallons of oil per ton in the unit is found in the General Petroleum well 5–31–G, sec. 31, T. 1 S., R. 96 W., where the shale attains a thickness of 220 feet.

Several zones in the oil-shale sequence below the Mahogany zone contain an average of 25 gallons of oil per ton in a continuous sequence 15 feet or more thick. These lower zones attain a maximum thickness of more than 1,500 feet. Near the junction of Black Sulfur and Piceance Creeks the Mahogany zone and the lower zones coalesce; elsewhere they are separated, in places by as much as 1,000 feet. These zones are known only from assays of rotary-drill cuttings from wells drilled for oil and gas. As far as is known, they underlie about 400 square miles in Tps. 1 N.–4 S., Rs. 95–99 W., in the northern part of the Piceance Creek basin.

Assays of cuttings from recent wells drilled for oil and gas indicate that former reserves estimates (Donnell, 1957a, p. 270) were conservative. Although no new detailed estimates of reserves from these lower zones have been made, it is estimated that there is at least 264,000 million tons of shale that contains about 157,000 million barrels of oil, or slightly more oil than the reserves estimated to be contained in the shale beds in and adjacent to the Mahogany zone that yield 25 gallons of oil per ton. These figures are in addition to the reserves computed for shale in the Mahogany zone and adjacent beds that yields 25 gallons of oil per ton (table 4).

Estimates of tonnage and oil content of that part of the Green River formation that yields an average of 15 gallons of oil per ton in a continuous sequence 15 feet or more thick are shown in table 5, and the distribution and thickness are shown on plate 54*D*. This unit includes the oil shale of all units previously discussed. Approximately 506 square miles of the area contain indicated reserves of about 818,000 million tons of oil shale with an oil content of 292,000 million barrels. An additional area of approximately 874 square miles contains inferred reserves of about 1,868,000 million tons of oil shale with an oil content of 667,000 million barrels. Rotary-drill samples from the General Petroleum well 5–31–G, sec. 31, T. 1 S., R. 96 W., just 10 miles west of the east limit of oil shale that is at least 15 feet thick (pl. 54*D*), indicate the presence of an oil-shale sequence 2,200 feet thick that yields an average of more than 15 gallons of oil per ton.

OIL AND GAS

DEVELOPMENT

In 1930, the Magnolia Petroleum Co. drilled the E. E. Fordham well 1–A in the SW¼ sec. 9, T. 2 S., R. 96 W., on the crest of the Piceance Creek anticline, to a total depth of 5,130 feet in the Wasatch formation. The well was plugged back to the Douglas Creek member of the Green River formation at about 3,000 feet and tested 2 million cubic feet of gas per day. In 1932, two more wells were drilled to the Douglas Creek member by the Magnolia Petroleum Co.—the Mildred M. Maddock in the NW¼SE¼ sec. 9, and the Gladys Titley 1 in the NW¼SW¼ sec. 15, both in T. 2 S., R. 96 W. These wells tested 7.4 million and 9.58 million cubic feet of gas per day, respectively. The General Petroleum Corp. later acquired Magnolia's acreage and between 1945 and 1951 drilled 12 additional wells on the Piceance Creek anticline, 8 of which tested commercial quantities of gas in the Douglas Creek member.

As development progressed the wells indicated that the well-defined surface structure has a different configuration at depth (p. 859), and gas accumulation initially thought to be controlled by the surface structure is now known to be trapped in sandstone lenses in the Douglas Creek member. The producing zone ranges from 12 to 230 feet in thickness and is in the Douglas Creek member.

The deepest test well in the field, the 84–15–G in sec. 15, T. 2 S., R. 96 W., was drilled to a total depth of 12,018 feet and bottomed near the middle of the Mesaverde group. No shows of oil or gas were found below the Green River formation, and the well was plugged back to the Douglas Creek member for completion.

A well was drilled in 1902 to a total depth of 1,066 feet on the De Beque anticline, a structure with a small amount of closure west of De Beque. The well, De Beque 1, had oil shows from two zones, probably from the lower part of the Wasatch formation or the upper part of the Mesaverde group, and produced a small quantity of oil for several days (Woodruff, 1913, p. 62–64). The oil shows in the De Beque 1 created considerable excitement, and 10 wells were drilled within 2 years. Nearly all the wells had some shows of oil and gas, and gas with water still escapes from the casing in the Wood well in the NW¼ sec. 29, T. 8 S., R. 97 W. The early drilling indicates that the oil and gas in shallow zones are trapped in lenticular sandstone beds and are not present in sufficient quantity to become commercial.

The Yellow Creek unit, northwest of the Piceance Creek gas field in Tps. 1 and 2 S., Rs. 97 and 98 W., and the De Beque anticline have recently been unsuccessfully tested for oil and gas. Wells in the Yellow Creek unit were drilled to total depths ranging between 2,500 and 4,000 feet and bottomed in the upper part of the Wasatch formation. Those on the De Beque anticline were drilled to total depths of about 3,500 feet and ended in the upper part of the Mancos shale, which underlies the Mesaverde group.

POSSIBILITIES

Oil and gas have been produced from the base of the Green River formation and the upper part of the Wasatch formation in several fields in the Uinta Basin in northeastern Utah. The oil has accumulated in both structural and stratigraphic traps and is believed to have migrated to its present position from the oil-shale units of the Green River formation (Picard, 1955, p. 80–82, table 2). The producing zones are at approximately the same stratigraphic position as the gas-producing zone in the Piceance Creek gas field. This zone appears favorable for much additional oil and gas exploration in the area of this report.

North of the mapped area, oil and gas are produced from the Wasatch and Fort Union formations in the Hiawatha and Powder Wash fields in the southern part of the Green River basin.

The Mesaverde group yields some oil and much gas in the Uinta, Green River, and Piceance Creek basins. This production is chiefly from the basal sandstone units of the Mesaverde group.

The Mancos, Dakota, Morrison, Entrada, Chinle (Shinarump member), and Weber formations, all of which underlie the area at depth produce oil and gas at various places in northwestern Colorado. Of these, the Weber sandstone of Pennsylvanian age is the most prolific oil producer. It crops out northwest, north, east, and southeast of the mapped area and is saturated with oil residue at many places. South of Rangely and west of the mapped area, wells drilled on the Douglas Creek anticline show that the Weber sandstone interfingers with and is replaced to the southwest by arkosic red beds. The Weber sandstone may contain oil under parts of the mapped area; however, a well would have to be drilled as deep as 20,000 feet in order to test the formation in the deepest part of the basin.

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TABLE 1.—*Core-drill holes, wells drilled for oil and gas, and surface sections shown on plate 48*

[Type of data: A, analyzed surface samples; C, core drill hole; D, dry hole; G, gas well; M, measured surface section.]

[Source of data: BM, U.S. Bureau of Mines; CO, Continental Oil Co.; COS, Columbia Oil Shale Co.; CSO Cities Service Oil Co.; FOS, Federal Oil Shale Co.; FP, Fremont Petroleum Co.; GP, General Petroleum Corp.; GS, U.S. Geological Survey; POC, Pure Oil Co.; PO, Pacific Oil Co.; PP, Phillips Petroleum Co.; SO, Sun Oil Co.; TE, Tell Ertl; UOC, Union Oil Co. of California; WO, Weber Oil Co., WOP, W. O. Pray.]

No. on pl. 48	Name or locality	Location			Type of data	Source of data	
		Sec.	T.	R.		Company, agency, or individual	Reference in which description or analyses published
1	A	NE¼SW¼ 12	6 S.	95 W.	C	BM	U.S. Bur. Mines Rept. Inv. 5081.
2	B	SE¼NW¼ 12	6 S.	95 W.	C	BM	Do.
3	C	SW¼NW¼ 12	6 S.	95 W.	C	BM	Do.
4	D	SW¼SW¼ 11	5 S.	95 W.	C	BM	Do.
5	E	SW¼NW¼ 2	5 S.	95 W.	C	BM	Do.
6	F	SE¼SE¼ 6	5 S.	94 W.	C	BM	Do.
7	G	SW¼NE¼ 3	5 S.	94 W.	C	BM	Do.
8	H	SE¼NW¼ 23	5 S.	95 W.	C	BM	Do.
9	I	SE¼NW¼ 20	5 S.	94 W.	C	BM	Do.
10	J	NW¼NW¼ 24	5 S.	94 W.	C	BM	Do.
11	K	SW¼SW¼ 5	6 S.	95 W.	C	BM	Do.
12	L	SW¼NW¼ 22	5 S.	94 W.	C	BM	Do.
13	M	SE¼NE¼ 22	5 S.	94 W.	C	BM	Do.
14	Sulfur Falls 1	SE¼NE¼ 2	4 S.	99 W.	C	WO	U.S. Bur. Mines Rept. Inv. 5321.
15	Summers Cabin 3	NE¼SE¼ 2	5 S.	97 W.	C	SO	Do.
16	Magor Camp 2	NW¼NW¼ 20	5 S.	97 W.	C	SO	Do.
17	Bear Run 1	NW¼NW¼ 25	5 S.	97 W.	C	SO	Do.
18	Magor 1	NW¼SW¼ 14	6 S.	98 W.	C	PO	Do.
19	Magor 2	SE¼NE¼ 7	6 S.	97 W.	C	PO	Do.
20	Magor 3	SW¼SW¼ 24	6 S.	98 W.	C	PO	Do.
21	Scott Fee 1	NE¼NE¼ 17	6 S.	98 W.	C	PO	Do.
22	Syndicate 1	SW¼NW¼ 11	5 S.	99 W.	C	PO	Do.
23	Syndicate 2	SW¼SW¼ 9	5 S.	98 W.	C	PO	Do.
24	Bella Castle 1	NW¼SE¼ 19	5 S.	95 W.	C	UOC	Do.
25	Lignum Vita 9	NW¼SE¼ 20	5 S.	95 W.	C	UOC	Do.
26	J.B.M. 6	NW¼SE¼ 10	6 S.	96 W.	C	UOC	Do.
27	Lignum Vita 13	SW¼NE¼ 21	5 S.	95 W.	C	UOC	Do.
28	Rett	NW¼NW¼ 28	4 S.	96 W.	C	UOC	Do.
29	Jill	NE¼NE¼ 22	4 S.	96 W.	C	UOC	Do.
30	Buff	NW¼SE¼ 23	4 S.	96 W.	C	UOC	Do.
31	Twig	SE¼SE¼ 35	4 S.	96 W.	C	UOC	Do.
32	Cascade 1	SW¼NW¼ 10	6 S.	97 W.	C	CSO	Do.
33	28-19-G	SW¼SW¼ 19	2 S.	95 W.	G	GP	U.S. Bur. Mines Rept. Inv. 5081.
34	66-5-G	NW¼SE¼ 5	2 S.	96 W.	G	GP	Do.
35	24-12-G	SW¼NW¼ 12	2 S.	96 W.	G	GP	Do.
36	84-15-G	SE¼NE¼ 15	2 S.	96 W.	G	GP	Do.
37	45X-29-G	NE¼SW¼ 29	2 S.	95 W.	G	GP	Do.
38	71X-29-G	NE¼NE¼ 29	2 S.	96 W.	D	GP	Do.
39	22-3-G	NW¼NW¼ 3	2 S.	96 W.	G	GP	Do.

TABLE 1.—*Core-drill holes, wells drilled for oil and gas, and surface sections shown on plate 48*—Continued

No. on pl. 48	Name or locality	Location			Type of data	Source of data	
		Sec.	T.	R.		Company, agency, or individual	Reference in which description or analyses published
40	24X-26-G	SW¼NW¼ 26	2 S.	96 W.	D	GP	U.S. Bur. Mines Rept. Inv. 5081
41	27-8-G	SW¼SW¼ 8	2 S.	95 W.	D	GP	
42	5-31-G	NW¼SW¼ 31	1 S.	96 W.	G	GP	Do.
43	45-32-G	NE¼SW¼ 32	2 S.	95 W.	D	GP	Do.
44	Figure 4 #1	SE¼NE¼ 10	4 S.	99 W.	O	WO	U.S. Bur. Mines Rept. Inv. 5321.
45	Joe T. 1	NW¼NW¼ 29	4 S.	99 W.	O	WO	Do.
46	Cow Ridge	19	7 S.	99 W.	M	GS	U.S. Geol. Survey Oil and Gas Inv. Map OM-114.
47	Dry Fork School	28, 29, 32	7 S.	98 W.	M	GS	Do.
48	Carr Creek	33, 34	5 S.	99 W.	M	GS	Do.
49	Upper Clear Creek	8, 17	5 S.	98 W.	M	GS	Do.
50	Old Highmore	23	6 S.	99 W.	M	GS	Do.
51	Deer Park Gulch	10, 11, 34	6 S.	98 W.	M	GS	Do.
52	East Fork Conn Creek.	16, 27 3, 4	6 S. 7 S.	97 W. 97 W.	M	GS	Do.
53	Bowdish Gulch	21, 22, 28	7 S.	97 W.	M	GS	Do.
54	Mount Callahan	15, 16, 20	7 S.	96 W.	M	GS	Do.
55	West Fork Parachute Creek.	10, 22, 23	5 S.	96 W.	M	GS	Do.
56	Hay Gulch	28, 29, 30, 31 36 1	1 N. 1 N. 1 S.	95 W. 96 W. 96 W.	M	GS	
57	Greasewood Gulch	32, 33 5	2 N. 1 N.	99 W. 99 W.	M	GS	
58	Upper Roan Creek	22	6 S.	100 W.	M	GS	
59	Black Sulfur Creek	26	3 S.	99 W.	M	GS	U.S. Geol. Survey Oil and Gas Inv. Map OM-134.
60	Lower Piceance Creek.	2, 11, 14	1 N.	97 W.	M	GS	
61	Fourteenmile Creek	6, 7 1, 12	3 S. 3 S.	94 W. 95 W.	M	GS	
62	Cathedral Creek	32	3 S.	99 W.	M	GS	U.S. Geol. Survey Oil and Gas Inv. Map OM-134.
63	Lake Creek	9	4 S.	100 W.	M	GS	Do.
64	Bear Creek	26	5 S.	100 W.	M	GS	Do.
65	Box Elder Creek	28	2 S.	100 W.	M	GS	Do.
66	Philadelphia Gulch	33 34	1 S. 2 S.	100 W. 100 W.	M	GS	Do.
67	Fletcher Gulch	18, 19	1 N.	99 W.	M	GS	Do.
68	Yellow Creek	9, 10, 15	2 N.	98 W.	M	GS	Do.
69	Coal Creek	6, 7, 18	8 S.	100 W.	M	GS	
70	East Middle Fork Parachute Creek.	16	5 S.	95 W.	M	GS	U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 94.
71	East Fork Parachute Creek.	20, 21, 28, 29	5 S.	95 W.	M	GS	Do.
72	Bull Gulch	35	5 S.	95 W.	M	GS	Do.
73	Glover Point	3, 22, 27, 28	6 S.	96 W.	M	GS	Do.
74	Allen Point	18, 19, 20	6 S.	95 W.	M	GS	Do.
75	Cottonwood Point	22, 23, 24	6 S.	95 W.	M	GS	Do.
76	Anvil Points	12, 13, 24	6 S.	95 W.	M	GS	Do.
77	Head of Golden Castle Creek.	25, 36	5 S.	94 W.	M	GS	Do.
78	Murphy's Trail	24	5 S.	94 W.	M	GS	Do.
79	Head of North Water Creek.	13, 14	5 S.	94 W.	M	GS	Do.
80	Head of Trappers Creek.	2, 10, 11	5 S.	95 W.	M	GS	Do.
81	Upper Piceance Creek.	5, 6	4 S.	94 W.	M	GS	U.S. Geol. Survey Oil and Gas Inv. Map OM-119.
82	Carr Creek	NE¼ 29	5 S.	99 W.	A	PP	U.S. Bur. Mines Rept. Inv. 5081.
83	51-28-G	NW¼NE¼ 28	1 S.	97 W.	D	GP	Not published.
84	Long Point	7	7 S.	97 W.	A	PP	U.S. Bur. Mines Rept. Inv. 5081.
85	Echo 3	SE¼SE¼ 21	7 S.	97 W.	A	FOS	Do.
86	Colombia	15, 16	5 S.	95 W.	A	COS	Do.
87	Conn Creek	SW¼NW¼ 17	6 S.	97 W.	A	POC	Do.
88	Piceance Creek	NE¼SW¼ 12	1 N.	97 W.	A	FP	Do.
89	do	SW cor. 12	1 N.	97 W.	A	FP	Do.

TABLE 1.—*Core-drill holes, wells drilled for oil and gas, and surface sections shown on plate 48*—Continued

No. on pl. 48	Name or locality	Location			Type of data	Source of data	
		Sec.	T.	R.		Company, agency, or individual	Reference in which description or analyses published
90	Hay Gulch	SW¼NE¼ 1	1 S.	96 W.	A	FP	U.S. Bur. Mines Rept. Inv. 5081.
91	do	SE¼ 2	1 S.	96 W.	A	FP	Do.
92	Cottonwood	9	5 S.	98 W.	A	FOS	Do.
93	Jackpot	24	6 S.	100 W.	A	PP	Do.
94	Cascade	NE¼ 16	6 S.	97 W.	A	PP	Do.
95	Clear Creek	NW cor. 18	5 S.	98 W.	A	POC	Do.
96	East Fork Conn Creek.	15	6 S.	97 W.	A	POC	Do.
97	West Cottonwood	7	5 S.	98 W.	A	POC	Do.
98	South Clear Creek	18	5 S.	98 W.	A	POC	Do.
99	Parks Ranch	26	5 S.	98 W.	A	POC	Do.
100	Cottonwood Point	NW¼SE¼ 22	6 S.	95 W.	A	BM	Do.
101	Allen Point	NW¼NW¼ 30	6 S.	95 W.	A	BM	Do.
102	Newton Point	3	6 S.	98 W.	A	FOS	Do.
103	Lindauer Point	E½ 19	5 S.	95 W.	A	UOC	Do.
104	Clear Creek	NW¼ 18	5 S.	98 W.	A	FOS	Do.
105	North Kimball	5	5 S.	100 W.	A	GS	U.S. Geol. Survey Bull. 729.
106	Big Spring Creek	25	1 N.	100 W.	A	GS	Do.
107	Yellow Creek	10	2 N.	98 W.	A	GS	Do.
108	Piceance Creek	11	1 N.	97 W.	A	GS	Do.
109	South Dry Fork	S½ 6	8 S.	99 W.	A	GS	Do.
110	North Dry Fork	27	7 S.	100 W.	A	GS	Do.
111	do	15	7 S.	100 W.	A	GS	Do.
112	Little Salt Wash	NE¼ 24	6 S.	101 W.	A	GS	Do.
113	Kimball	31	6 S.	100 W.	A	GS	Do.
114	do	6	7 S.	100 W.	A	GS	Do.
115	Brush Creek	31	4 S.	99 W.	A	GS	Do.
116	Carr Creek	9	5 S.	100 W.	A	GS	Do.
117	Black Sulfur Creek	17	4 S.	99 W.	A	GS	Do.
118	Tommies Draw	14	3 S.	100 W.	A	GS	Do.
119	Duck Creek	19	1 S.	99 W.	A	GS	Do.
120	West Spring Creek	16	1 S.	100 W.	A	GS	Do.
121	G. M. Cut 38	SE¼SE¼NW¼ 5.	7 S.	99 W.	A	WOP	Not published.
122	Ute 1	NE¼NW¼ 28	3 S.	99 W.	C	WO	U.S. Bur. Mines Rept. Inv. 5321.
123	Juhan 1	W½W½ 1	1 S.	96 W.	C	WO	Do.
124	Ute 2	NE¼SE¼ 33	3 S.	99 W.	C	WO	Do.
125	Black Sulfur Falls 2	SW¼NE¼ 26	3 S.	99 W.	C	WO	Do.
126	Marcedus 1	SE¼SE¼ 31	3 S.	98 W.	C	WO	Do.
127	Marcedus 2	SE¼NW¼ 30	3 S.	98 W.	C	WO	Do.
128	G. J. 1	NE¼SE¼ 22	2 S.	100 W.	C	WO	Do.
129	G. J. 2	SE¼NE¼ 34	2 S.	100 W.	C	WO	Do.
130	G. J. 3	NE¼NW¼ 2	3 S.	100 W.	C	WO	Do.
131	64-84-G	SE¼SW¼ NE¼ 8.	1 N.	98 W.	D	GP	Not published.
132	46-27-G	SE¼NE¼ SW¼ 27.	1 N.	98 W.	D	GP	Do.
133	Jann	NW¼NW¼ 19	2 S.	99 W.	C	TE	U.S. Bur. Mines Rept. Inv. 5321, table 2, p. 13.
134	Ray	SW¼NW¼ 21	1 S.	100 W.	C	TE	Do.
135	Phil	NW¼NE¼ 25	1 S.	100 W.	C	TE	Do.
136	Matt	SW¼SW¼ 33	1 S.	100 W.	C	TE	Do.
137	Coscora 2	SW¼SE¼ 23	4 S.	99 W.	C	WO	U.S. Bur. Mines Rept. Inv. 5321.
138	Figure 4 #3	NE¼NE¼ 17	4 S.	99 W.	C	WO	Do.
139	Figure 4 #2	SW¼NW¼ 15	4 S.	99 W.	C	WO	Do.
140	Eureca 1	SE¼SE¼ 13	4 S.	99 W.	C	WO	Do.
141	War Eagle 1	SE¼SE¼ 20	4 S.	99 W.	C	WO	Do.
142	Coscora 1	NW¼NE¼ 14	4 S.	99 W.	C	WO	Do.
143	Black Eagle 1	SW¼SE¼ 6	4 S.	99 W.	C	WO	Do.
144	Whatley 3	SE¼SE¼ 36	6 S.	100 W.	C	CO	Do.
145	2	Cen. east side NE¼NE¼ 4	7 S.	99 W.	C	CO	Do.
146	1	SW¼SE¼ 1	7 S.	99 W.	C	CO	Do.

TABLE 2.—*Estimated tonnage and potential oil content of the part of the Mahogany zone that yields an average of 45 gallons of oil per ton in a continuous sequence 5 feet or more thick* [1]

[No allowance made for losses in mining and processing]

Location T.	Location R.	Area (acres)	Average thickness of oil shale (feet)	Average tonnage of oil shale per acre (thousands of tons)	Average oil yield per acre (thousands of barrels)	Tonnage of oil shale (millions of tons)	Oil yield (millions of barrels)
Indicated reserves							
4 S	94 W	2, 570	15	40. 2	43. 0	103	111
4 S	95 W	9, 310	26	69. 6	74. 5	648	694
4 S	99 W	10, 068	6	16. 1	17. 2	162	173
5 S	94 W	17, 100	15	40. 2	43. 0	687	735
5 S	95 W	19, 410	20	53. 6	57. 4	1, 040	1, 114
5 S	96 W	18, 350	15	40. 2	43. 0	738	789
5 S	97 W	19, 225	10	26. 8	28. 7	515	552
5 S	98 W	9, 930	10	26. 8	28. 7	266	285
5 S	99 W	2, 200	6	16. 1	17. 2	35	38
6 S	94 W	647	11	29. 5	31. 6	19	20
6 S	95 W	10, 820	15	40. 2	43. 0	435	465
6 S	96 W	8, 790	18	48. 2	51. 6	424	454
6 S	97 W	17, 190	17	45. 6	48. 8	784	839
6 S	98 W	6, 730	9	24. 1	25. 8	162	174
6 S	99 W	2, 820	6	16. 1	17. 2	45	49
6 S	100 W	59	5	13. 4	14. 3	0. 8	0. 8
7 S	96 W	2, 080	9	24. 1	25. 8	50	54
7 S	97 W	6, 590	10	26. 8	28. 7	177	189
7 S	98 W	1, 030	9	24. 1	25. 8	25	27
7 S	99 W	2, 070	8	21. 4	22. 9	44	47
7 S	100 W	119	5	13. 4	14. 3	1. 6	1. 7
Total		167, 108				6, 361. 4	6, 811. 5
Inferred reserves							
4 S	94 W	2, 290	10	26. 8	28. 7	61	66
4 S	95 W	13, 050	16	42. 9	45. 9	560	599
7 S	98 W	830	7	18. 8	20. 1	16	17
7 S	99 W	981	7	18. 8	20. 1	18	20
Total		17, 151				655	702

[1] Distribution and thickness of zone shown on plate 54*A*.

TABLE 3.—*Estimated tonnage and potential oil content of oil shale in and adjacent to the Mahogany zone that yields an average of 30 gallons of oil per ton in a continuous sequence 15 feet or more thick* [1]

[Totals include reserves tabulated in table 2. No allowance made for losses in mining and processing]

Location T.	Location R.	Area (acres)	Average thickness of oil shale (feet)	Average tonnage of oil shale per acre (thousands of tons)	Average oil yield per acre (thousands of barrels)	Tonnage of oil shale (millions of tons)	Oil yield (millions of barrels)
Indicated reserves							
1 S	96 W	2, 212	30	88. 8	63. 4	196	140
1 S	99 W	3, 162	52	153. 9	109. 9	487	348
1 S	100 W	7, 264	35	103. 6	74. 0	753	538
2 S	99 W	5, 926	43	127. 3	90. 9	754	539
2 S	100 W	12, 192	35	103. 6	74. 0	1, 263	902
3 S	98 W	4, 570	75	222. 0	158. 6	1, 015	725
3 S	99 W	20, 070	51	151. 0	107. 8	3, 031	2, 165
3 S	100 W	2, 800	36	106. 6	76. 1	298	213
4 S	94 W	2, 750	60	177. 6	126. 9	488	349
4 S	95 W	7, 330	100	296. 0	211. 4	2, 170	1, 550
4 S	96 W	5, 215	88	260. 5	186. 1	1, 359	971
4 S	97 W	4, 550	82	242. 7	173. 4	1, 104	789
4 S	98 W	11, 392	65	192. 4	137. 4	2, 192	1, 566
4 S	99 W	22, 592	44	130. 2	93. 0	2, 941	2, 101
4 S	100 W	1, 796	29	85. 8	61. 3	154	110
5 S	94 W	17, 187	60	177. 6	126. 9	3, 052	2, 180
5 S	95 W	19, 410	90	266. 4	190. 3	5, 171	3, 694
5 S	96 W	18, 350	85	251. 6	179. 7	4, 617	3, 298
5 S	97 W	21, 600	67	198. 3	141. 7	4, 283	3, 059
5 S	98 W	16, 810	48	142. 1	101. 5	2, 389	1, 707
5 S	99 W	13, 000	40	118. 4	84. 6	1, 539	1, 099
6 S	94 W	647	55	162. 8	116. 3	105	75
6 S	95 W	10, 820	78	230. 9	164. 9	2, 498	1, 784
6 S	96 W	8, 790	85	251. 6	179. 7	2, 212	1, 580
6 S	97 W	17, 190	75	222. 0	158. 6	3, 816	2, 726
6 S	98 W	8, 650	55	162. 8	116. 3	1, 408	1, 006
6 S	99 W	5, 460	40	118. 4	84. 6	646	461
6 S	100 W	2, 055	18	53. 3	38. 1	110	79
7 S	96 W	2, 080	47	139. 1	99. 3	289	207
7 S	97 W	6, 590	47	139. 1	99. 3	917	655
7 S	98 W	1, 030	35	103. 6	74. 0	107	77
7 S	99 W	2, 070	32	94. 7	67. 6	196	140
7 S	100 W	209	17	50. 3	35. 9	11	8
Totals		285, 769				51, 571	36, 841

[1] Distribution and thickness of zone shown on plate 54*B*.

TABLE 3.—*Estimated tonnage and potential oil content of oil shale in and adjacent to the Mahogany zone that yields an average of 30 gallons of oil per ton in a continuous sequence 15 feet or more thick* [1]—Continued

[Totals include reserves tabulated in table 2. No allowance made for losses in mining and processing]

Location T.	Location R.	Area (acres)	Average thickness of oil shale (feet)	Average tonnage of oil shale per acre (thousands of tons)	Average oil yield per acre (thousands of barrels)	Tonnage of oil shale (millions of tons)	Oil yield (millions of barrels)
Inferred reserves							
2 N	97 W	446	20	59. 2	42. 3	26	19
2 N	98 W	8, 582	25	74. 0	52. 9	635	454
2 N	99 W	3, 578	21	62. 2	44. 4	223	159
1 N	96 W	3, 424	25	74. 0	52. 9	253	181
1 N	97 W	18, 112	45	133. 2	95. 1	2, 413	1, 724
1 N	98 W	22, 920	64	189. 4	135. 3	4, 341	3, 101
1 N	99 W	20, 288	36	106. 6	76. 1	2, 163	1, 545
1 N	100 W	445	17	50. 3	35. 9	22	16
1 S	95 W	565	17	50. 3	35. 9	28	20
1 S	96 W	20, 384	90	266. 4	190. 3	5, 430	3, 879
1 S	97 W	28, 320	79	233. 8	167. 0	6, 621	4, 729
1 S	98 W	24, 860	69	204. 2	145. 9	5, 076	3, 626
1 S	99 W	22, 038	56	165. 8	118. 4	3, 654	2, 610
1 S	100 W	2, 246	25	74. 0	52. 9	166	119
2 S	95 W	7, 050	25	74. 0	52. 9	522	373
2 S	96 W	23, 400	35	103. 6	74. 0	2, 424	1, 731
2 S	97 W	23, 925	72	213. 1	152. 2	5, 098	3, 641
2 S	98 W	23, 450	61	180. 6	129. 0	4, 235	3, 025
2 S	99 W	17, 783	50	148. 0	105. 7	2, 632	1, 880
3 S	94 W	579	22	65. 1	46. 5	38	27
3 S	95 W	18, 420	32	94. 7	67. 7	1, 744	1, 246
3 S	96 W	23, 477	51	151. 0	107. 9	3, 545	2, 532
3 S	97 W	24, 210	74	219. 0	156. 4	5, 302	3, 787
3 S	98 W	19, 264	72	213. 1	152. 2	4, 105	2, 932
3 S	99 W	1, 594	54	159. 8	114. 1	255	182
4 S	94 W	5, 020	40	118. 4	84. 6	594	424
4 S	95 W	15, 290	80	236. 8	169. 1	3, 621	2, 587
4 S	96 W	17, 025	77	227. 9	162. 8	3, 880	2, 771
4 S	97 W	18, 750	78	230. 9	164. 9	4, 329	3, 092
4 S	98 W	11, 840	75	222. 0	158. 6	2, 628	1, 877
4 S	99 W	208	23	68. 1	48. 7	14	10
4 S	100 W	3, 033	19	56. 2	40. 1	170	121
5 S	99 W	3, 110	20	59. 2	42. 3	184	131
5 S	100 W	223	16	47. 4	33. 9	11	8
7 S	98 W	830	25	74. 0	52. 9	61	43
7 S	99 W	1, 460	20	59. 2	42. 3	86	61
Totals		436, 149				76, 529	54, 663

[1] Distribution and thickness of zone shown on plate 54*B*.

TABLE 4.—*Estimated tonnage and potential oil content of oil shale in and adjacent to the Mahogany zone that yields an average of 25 gallons of oil per ton in a continuous sequence 15 feet or more thick*[1]

[Totals include reserves tabulated in table 3. No allowance made for losses in mining or processing]

Location T.	Location R.	Area (acres)	Average thickness of oil shale (feet)	Average tonnage of oil shale per acre (thousands of tons)	Average oil yield per acre (thousands of barrels)	Tonnage of oil shale (millions of tons)	Oil yield (millions of barrels)
Indicated reserves							
1 N	96 W	134	17	52. 2	31. 1	7	4
1 S	95 W	104	18	55. 3	32. 9	6	3
1 S	96 W	3, 495	30	92. 1	54. 8	322	192
1 S	99 W	3, 162	101	310. 1	184. 6	980	583
1 S	100 W	7, 264	65	199. 6	118. 8	1, 450	863
2 S	99 W	5, 926	90	276. 3	164. 5	1, 637	974
2 S	100 W	12, 192	70	214. 9	127. 9	2, 620	1, 559
3 S	98 W	4, 570	130	399. 1	237. 5	1, 824	1, 086
3 S	99 W	20, 070	98	300. 8	179. 0	6, 037	3, 593
3 S	100 W	2, 800	65	199. 6	118. 8	559	333
4 S	94 W	3, 020	80	245. 6	146. 2	742	442
4 S	95 W	7, 330	150	460. 5	274. 1	3, 375	2, 009
4 S	96 W	5, 215	140	429. 8	255. 8	2, 241	1, 334
4 S	97 W	4, 550	145	445. 2	265. 0	2, 026	1, 206
4 S	98 W	11, 392	95	291. 7	173. 6	3, 323	1, 978
4 S	99 W	22, 592	85	261. 0	155. 3	5, 897	3, 510
4 S	100 W	1, 796	45	138. 1	82. 2	248	148
5 S	94 W	18, 131	90	276. 3	164. 5	5, 010	2, 982
5 S	95 W	19, 410	150	460. 5	274. 1	8, 938	5, 320
5 S	96 W	18, 350	140	429. 8	255. 8	7, 887	4, 694
5 S	97 W	21, 600	120	368. 4	219. 3	7, 957	4, 736
5 S	98 W	16, 810	100	307. 0	182. 7	5, 161	3, 072
5 S	99 W	13, 000	70	214. 9	127. 9	2, 794	1, 663
6 S	94 W	647	80	245. 6	146. 2	159	95
6 S	95 W	10, 820	120	368. 4	219. 3	3, 986	2, 372
6 S	96 W	8, 790	135	414. 5	246. 7	3, 643	2, 168
6 S	97 W	17, 190	130	399. 1	237. 5	6, 861	4, 084
6 S	98 W	8, 650	95	291. 7	173. 6	2, 523	1, 502
6 S	99 W	5, 460	75	230. 3	137. 1	1, 257	748
6 S	100 W	2, 560	30	92. 1	54. 8	236	141
7 S	96 W	2, 080	80	245. 6	146. 2	511	304
7 S	97 W	6, 590	90	276. 3	164. 5	1, 821	1, 084
7 S	98 W	1, 030	85	261. 0	155. 3	269	160
7 S	99 W	2, 070	75	230. 3	137. 1	477	284
7 S	100 W	538	25	76. 8	45. 7	41	25
Totals		289, 338				92, 825	55, 251

[1] Distribution and thickness of zone shown on plate 54*C*.

TABLE 4.—*Estimated tonnage and potential oil content of oil shale in and adjacent to the Mahogany zone that yields an average of 25 gallons of oil per ton in a continuous sequence 15 feet or more thick* [1]—Continued

[Totals include reserves tabulated in table 3. No allowance made for losses in mining or processing]

Location T.	Location R.	Area (acres)	Average thickness of oil shale (feet)	Average tonnage of oil shale per acre (thousands of tons)	Average oil yield per acre (thousands of barrels)	Tonnage of oil shale (millions of tons)	Oil yield (millions of barrels)
Inferred reserves							
2 N	97 W	1, 488	30	92. 1	54. 8	137	81
2 N	98 W	13, 152	60	184. 2	109. 6	2, 423	1, 442
2 N	99 W	6, 272	40	122. 8	73. 1	770	458
1 N	96 W	4, 448	40	122. 8	73. 1	546	325
1 N	97 W	19, 872	70	214. 9	127. 9	4, 270	2, 541
1 N	98 W	22, 920	162	497. 3	296. 0	11, 398	6, 784
1 N	99 W	22, 756	85	261. 0	155. 3	5, 939	3, 535
1 N	100 W	1, 440	30	122. 8	73. 1	177	105
1 S	95 W	2, 080	25	76. 8	45. 7	16	9
1 S	96 W	20, 384	120	368. 4	219. 3	7, 509	4, 469
1 S	97 W	28, 320	195	598. 7	356. 3	16, 955	10, 092
1 S	98 W	24, 860	165	506. 6	301. 5	12, 594	7, 496
1 S	99 W	22, 038	118	371. 5	221. 1	8, 187	4, 873
1 S	100 W	2, 246	38	107. 5	64. 0	241	143
2 S	95 W	12, 480	35	107. 5	64. 0	1, 342	799
2 S	96 W	23, 400	90	276. 3	164. 5	6, 465	3, 848
2 S	97 W	23, 925	145	445. 2	265. 0	10, 651	6, 339
2 S	98 W	23, 450	140	429. 8	255. 8	10, 079	5, 999
2 S	99 W	17, 783	112	334. 6	199. 2	5, 950	3, 541
3 S	95 W	19, 100	50	153. 5	91. 4	2, 932	1, 745
3 S	96 W	23, 477	125	383. 8	228. 4	9, 011	5, 363
3 S	97 W	24, 210	145	445. 2	265. 0	10, 778	6, 415
3 S	98 W	19, 264	125	383. 8	228. 4	7, 394	4, 401
3 S	99 W	1, 594	112	343. 8	204. 6	548	326
4 S	94 W	3, 935	45	138. 2	82. 3	544	324
4 S	95 W	15, 290	142	435. 9	259. 5	6, 665	3, 967
4 S	96 W	17, 025	140	429. 8	255. 9	7, 317	4, 355
4 S	97 W	18, 750	150	460. 5	274. 1	8, 634	5, 139
4 S	98 W	11, 840	122	374. 5	222. 9	4, 434	2, 639
4 S	99 W	208	32	98. 2	58. 5	20	12
4 S	100 W	11, 072	27	82. 9	49. 4	918	546
5 S	99 W	3, 110	37	113. 6	67. 7	353	210
5 S	100 W	9, 050	25	76. 8	45. 7	695	414
6 S	100 W	4, 025	20	61. 4	36. 6	247	147
7 S	98 W	830	60	184. 2	109. 7	153	91
7 S	99 W	1, 995	40	122. 8	73. 1	245	146
7 S	100 W	1, 999	20	61. 4	36. 6	123	73
8 S	99 W	865	20	61. 4	36. 6	53	32
Totals		480, 953				166, 713	99, 233

[1] Distribution and thickness of zone shown on plate 54*C*.

TABLE 5.—*Estimated tonnage and potential oil content of oil shale that yields an average of 15 gallons of oil per ton in a continuous sequence 15 feet or more thick* [1]

[Totals include reserves tabulated in table 4. No allowance made for losses in mining or processing]

Location T.	Location R.	Area (acres)	Average thickness of oil shale (feet)	Average tonnage of oil shale per acre (thousands of tons)	Average oil yield per acre (thousands of barrels)	Tonnage of oil shale (millions of tons)	Oil yield (millions of barrels)
			Indicated reserves				
2 N	98 W	535	1, 575	5, 181. 8	1, 850. 4	2, 772	990
1 N	96 W	1, 250	100	329. 0	117. 5	411	147
1 N	98 W	7, 104	2, 000	6, 580. 0	2, 349. 7	46, 744	16, 693
1 N	99 W	148	1, 725	5, 675. 3	2, 026. 6	840	300
1 S	95 W	294	175	575. 8	205. 6	169	60
		965	60	197. 8	70. 6	191	68
1 S	96 W	3, 860	300	986. 8	352. 4	3, 809	1, 361
		7, 430	1, 700	5, 593. 0	1, 997. 3	41, 556	14, 840
1 S	97 W	2, 825	2, 150	7, 073. 5	2, 525. 9	19, 983	7, 136
2 S	95 W	16, 450	300	987. 0	352. 5	16, 236	5, 798
2 S	96 W	20, 400	1, 950	6, 415. 5	2, 291. 0	130, 876	46, 736
2 S	97 W	1, 325	2, 050	6, 744. 5	2, 408. 5	8, 936	3, 191
2 S	99 W	768	550	1, 809. 5	646. 2	1, 390	496
2 S	100 W	8, 584	275	904. 8	323. 1	7, 767	2, 774
3 S	94 W	580	50	164. 5	58. 7	95	34
3 S	95 W	8, 455	450	1, 480. 5	528. 7	12, 518	4, 470
		864	150	493. 5	176. 2	426	152
3 S	96 W	1, 427	1, 500	4, 935. 0	1, 762. 3	7, 042	2, 515
3 S	99 W	10, 825	700	2, 303. 0	822. 4	24, 930	8, 903
3 S	100 W	3, 170	350	1, 151. 5	411. 2	3, 650	1, 303
4 S	94 W	7, 100	180	592. 3	211. 5	4, 205	1, 502
4 S	95 W	7, 330	720	2, 368. 8	845. 9	17, 363	6, 200
4 S	96 W	5, 215	1, 150	3, 783. 5	1, 351. 1	19, 731	7, 046
4 S	97 W	2, 465	1, 300	4, 277. 1	1, 527. 3	10, 543	3, 765
4 S	98 W	3, 950	850	2, 796. 5	998. 6	11, 046	3, 945
4 S	99 W	21, 914	650	2, 138. 5	763. 7	46, 863	16, 735
4 S	100 W	1, 952	450	1, 480. 5	528. 7	2, 890	1, 032
5 S	94 W	18, 265	400	1, 316. 0	469. 9	24, 037	8, 584
5 S	95 W	20, 950	760	2, 500. 4	892. 9	52, 383	18, 706
5 S	96 W	20, 610	930	3, 059. 7	1, 092. 6	63, 060	22, 519
5 S	97 W	21, 610	910	2, 993. 9	1, 069. 1	64, 698	23, 104
5 S	98 W	19, 450	650	2, 138. 5	763. 7	41, 594	14, 853
5 S	99 W	13, 568	475	1, 562. 8	558. 1	21, 204	7, 572
6 S	94 W	684	450	1, 481. 0	528. 9	1, 013	362
6 S	95 W	10, 320	560	1, 842. 4	657. 9	19, 014	6, 790
6 S	96 W	9, 850	625	2, 056. 2	734. 3	20, 254	7, 233
6 S	97 W	14, 790	630	2, 072. 7	740. 2	30, 655	10, 947
6 S	98 W	11, 990	525	1, 727. 3	616. 8	20, 710	7, 395
6 S	99 W	7, 780	400	1, 316. 0	469. 9	10, 238	3, 656
6 S	100 W	2, 945	250	822. 5	293. 7	2, 423	865
7 S	98 W	970	400	1, 316. 0	469. 9	1, 277	456
7 S	99 W	2, 100	325	1, 069. 0	381. 7	2, 245	802
7 S	100 W	717	175	576. 0	205. 7	413	147
Totals		323, 784				818, 200	292, 183

[1] Distribution and thickness of zone shown on plate 54*D*.

TABLE 5.—*Estimated tonnage and potential oil content of oil shale that yields an average of 15 gallons of oil per ton in a continuous sequence 15 feet or more thick* [1]—Continued

[Totals include reserves tabulated in table 4. No allowance made for losses in mining or processing]

Location T.	Location R.	Area (acres)	Average thickness of oil shale (feet)	Average tonnage of oil shale per acre (thousands of tons)	Average oil yield per acre (thousands of barrels)	Tonnage of oil shale (millions of tons)	Oil yield (millions of barrels)
			Inferred reserves				
2 N	97 W	2, 445	200	658. 0	235. 0	1, 609	575
2 N	98 W	14, 272	675	2, 220. 8	793. 0	31, 695	11, 318
2 N	99 W	10, 570	200	658. 0	235. 0	6, 955	2, 484
2 N	100 W	211	20	65. 8	23. 5	14	5
1 N	96 W	9, 410	150	493. 5	176. 2	4, 644	1, 658
1 N	97 W	20, 950	900	2, 961. 0	1, 057. 4	62, 033	22, 152
1 N	98 W	16, 256	2, 025	6, 662. 3	2, 379. 1	108, 302	38, 675
1 N	99 W	23, 002	950	3, 125. 5	1, 116. 1	71, 893	25, 673
1 N	100 W	4, 320	225	740. 3	264. 4	3, 198	1, 142
1 S	95 W	8, 090	80	263. 2	94. 0	2, 129	760
1 S	96 W	13, 350	1, 000	3, 290. 0	1, 174. 9	43, 922	15, 685
1 S	97 W	25, 495	2, 050	6, 744. 5	2, 408. 5	171, 951	61, 404
1 S	98 W	24, 860	1, 975	6, 498. 7	2, 320. 7	161, 558	57, 692
1 S	99 W	25, 200	1, 150	3, 783. 5	1, 351. 1	95, 344	34, 047
1 S	100 W	17, 700	225	740. 3	264. 4	13, 103	4, 679
2 S	95 W	3, 485	50	164. 4	58. 7	573	205
2 S	96 W	3, 355	1, 850	6, 086. 4	2, 173. 5	20, 420	7, 292
2 S	97 W	22, 600	1, 775	5, 839. 8	2, 085. 4	131, 979	47, 130
2 S	98 W	23, 450	1, 575	5, 181. 7	1, 850. 4	121, 511	43, 391
2 S	99 W	22, 232	1, 050	3, 454. 5	1, 233. 6	76, 800	27, 425
2 S	100 W	4, 516	250	822. 5	293. 7	3, 714	1, 326
3 S	94 W	160	20	65. 8	23. 5	11	4
3 S	95 W	14, 000	600	1, 974. 0	704. 9	27, 636	9, 869
3 S	96 W	22, 050	1, 600	5, 264. 0	1, 879. 8	116, 071	41, 449
3 S	97 W	24, 210	1, 500	4, 935. 0	1, 762. 3	119, 476	42, 665
3 S	98 W	23, 550	1, 250	4, 112. 5	1, 468. 6	96, 849	34, 585
3 S	99 W	11, 428	975	3, 208. 7	1, 145. 9	36, 669	13, 094
4 S	94 W	3, 600	150	493. 5	176. 3	1, 777	635
4 S	95 W	15, 290	700	2, 303. 0	822. 4	35, 213	12, 575
4 S	96 W	17, 025	1, 200	3, 948. 0	1, 409. 9	67, 215	24, 002
4 S	97 W	20, 750	1, 250	4, 112. 5	1, 468. 6	85, 334	30, 473
4 S	98 W	18, 510	1, 000	3, 290. 0	1, 174. 9	60, 898	21, 747
4 S	99 W	256	450	1, 480. 5	528. 7	379	135
4 S	100 W	12, 898	350	1, 151. 5	411. 2	14, 852	5, 304
5 S	97 W	1, 190	975	3, 207. 6	1, 145. 5	3, 817	1, 363
5 S	98 W	743	850	2, 796. 8	998. 8	2, 078	742
5 S	99 W	5, 527	350	1, 151. 5	411. 2	6, 364	2, 273
5 S	100 W	18, 410	200	658. 0	235. 0	12, 114	4, 326
6 S	95 W	1, 010	575	1, 892. 1	675. 7	1, 911	683
6 S	96 W	1, 804	590	1, 941. 2	693. 3	3, 502	1, 251

[1] Distribution and thickness of zone shown on plate 54*D*.

TABLE 5.—*Estimated tonnage and potential oil content of oil shale that yields an average of 15 gallons of oil per ton in a continuous sequence 15 feet or more thick*[1]—Continued

[Totals include reserves tabulated in table 4. No allowance made for losses in mining or processing]

Location T.	Location R.	Area (acres)	Average thickness of oil shale (feet)	Average tonnage of oil shale per acre (thousands of tons)	Average oil yield per acre (thousands of barrels)	Tonnage of oil shale (millions of tons)	Oil yield (millions of barrels)
Inferred reserves							
6 S	97 W	5, 100	510	1, 677. 8	599. 2	8, 557	3, 056
6 S	100 W	7, 580	150	493. 5	176. 3	3, 741	1, 336
6 S	101 W	4, 710	85	279. 7	99. 9	1, 317	471
7 S	96 W	4, 140	425	1, 398. 3	499. 4	5, 789	2, 067
7 S	97 W	9, 550	425	1, 398. 3	499. 4	13, 354	4, 769
7 S	98 W	2, 320	325	1, 069. 4	381. 9	2, 481	886
7 S	99 W	3, 070	200	658. 0	235. 0	2, 020	721
7 S	100 W	9, 000	100	329. 0	117. 5	2, 961	1, 057
7 S	101 W	2, 175	55	181. 1	64. 7	394	141
8 S	99 W	2, 250	150	493. 5	176. 3	1, 110	396
8 S	100 W	1, 120	90	296. 1	105. 8	332	119
Total		559, 195				1,867,569	666, 911

[1] Distribution and thickness of zone shown on plate 54*D*.

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