DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
W. E. WRATHER, DIRECTOR

OM 134

WILLIAM J. HAIL

OIL AND GAS INVESTIGATIONS
MAP OM134

GEOLOGY OF THE CATHEDRAL BLUFFS OIL-SHALE AREA, RIO BLANCO AND GARFIELD COUNTIES, COLORADO

By J. R. Donnell, W. B. Cashion, and James H. Brown, Jr.

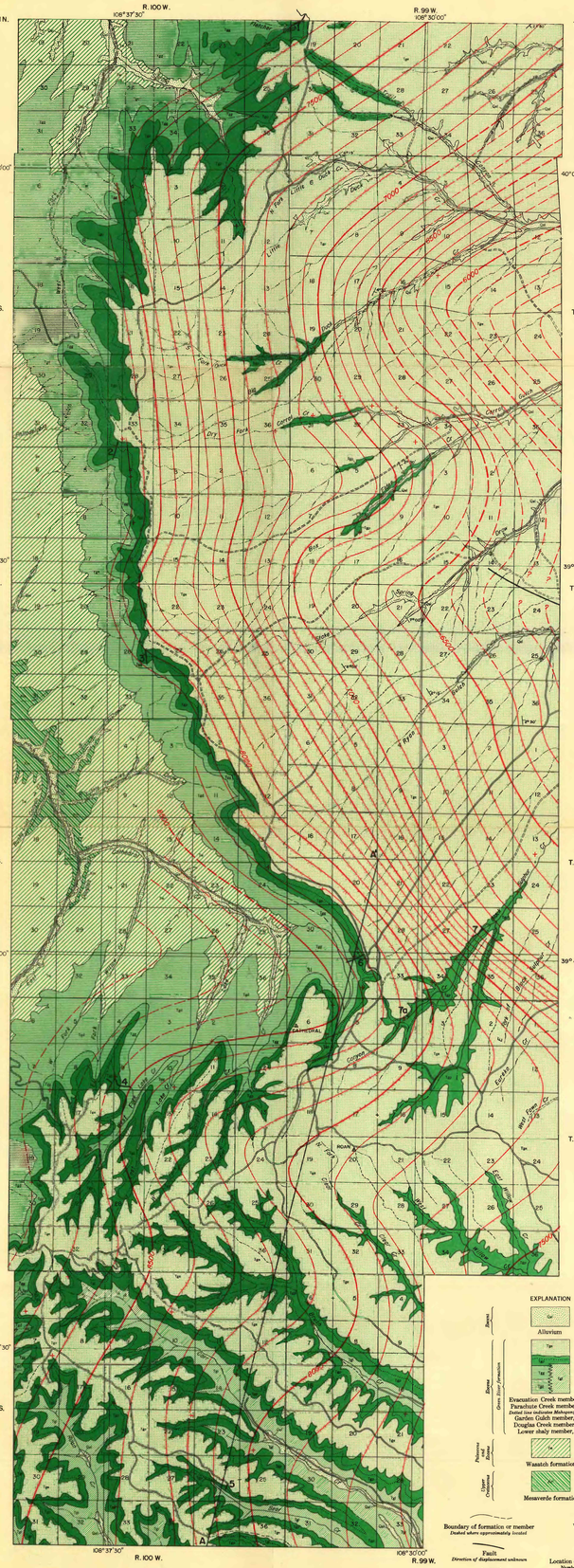
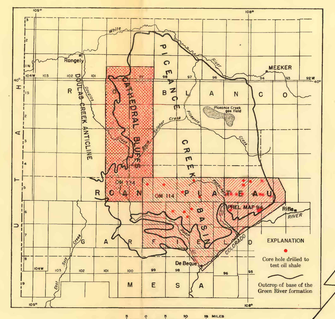


FIGURE 2. INDEX MAP OF PART OF WESTERN COLORADO SHOWING RELATION OF AREA IN THIS REPORT TO AREAS DESCRIBED IN U. S. GEOLOGICAL SURVEY OIL AND GAS INVESTIGATIONS SERIES.
PRELIMINARY MAP 94 AND OIL MAP 114



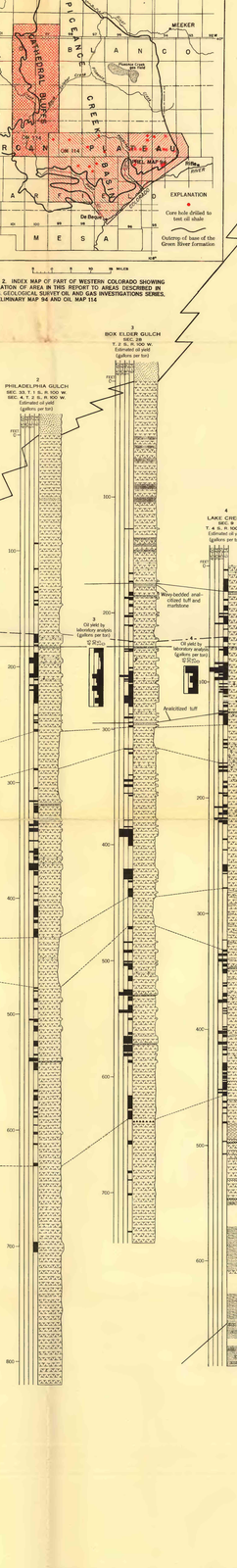


FIGURE 1. STRATIGRAPHIC SECTIONS OF PART OF THE GREEN RIVER FORMATION, SHOWING CORRELATIONS OF OIL-SHALE ZONES, MEMBERS AND KEY BEDS, AND OIL YIELDS. LOCATIONS OF SECTIONS ARE SHOWN ON GEOLOGIC MAP.

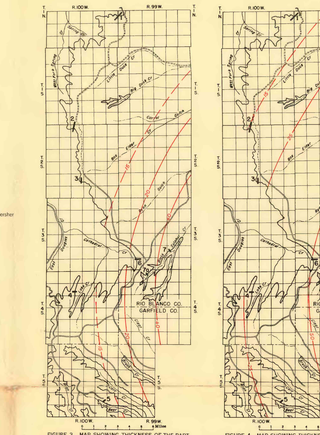


FIGURE 3. MAP SHOWING THICKNESS OF THE PART OF THE MAHOGANY LEDGE THAT YIELDS AN AVERAGE OF 50 GALLONS OF OIL PER TON

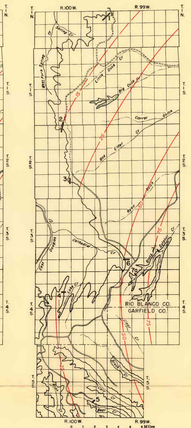


FIGURE 4. MAP SHOWING THICKNESS OF THE PART OF THE MAHOGANY LEDGE THAT YIELDS AN AVERAGE OF 25 GALLONS OF OIL PER TON

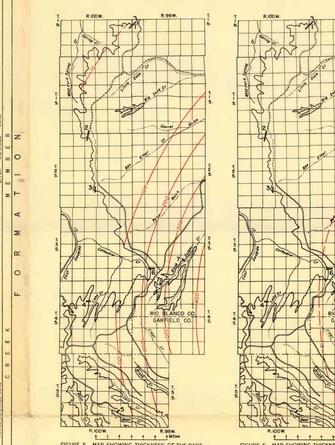


FIGURE 5. MAP SHOWING THICKNESS OF THE PART OF THE UPPER OIL-SHALE ZONE THAT YIELDS AN AVERAGE OF 15 GALLONS OF OIL PER TON

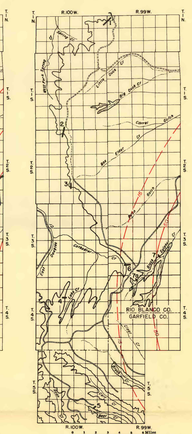
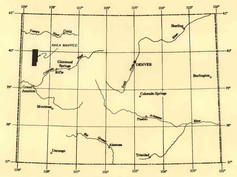


FIGURE 6. MAP SHOWING THICKNESS OF THE PART OF THE MIDDLE OIL-SHALE ZONE THAT YIELDS AN AVERAGE OF 15 GALLONS OF OIL PER TON



EXPLANATION

100 — Line connecting points of equal thickness, in feet, of oil shale

20 — Minimum thickness, in feet, upon which reserves were computed

Outcrop of Mahogany bed

1 — Location of measured stratigraphic section. Numbers correspond to numbers of sections on fig. 1.

INTRODUCTION

The Cathedral Bluffs oil-shale area, in Garfield and Rio Blanco Counties, western Colorado, occupies approximately 305 square miles on the western margin of the Piceance Creek Basin. The present study of the Cathedral Bluffs oil-shale area was made by the U. S. Geological Survey as a part of the oil-shale investigations conducted by the Survey in parts of appraisal of the more promising oil-shale deposits in the United States. A field party was consisted of J. R. Donnell, W. B. Cashion, W. M. Zilhersher, and R. C. Gibson, assisted part time by M. G. Wolman, mapped the area in 1950. F. E. Walton spent two weeks with the party at the beginning of the season, and Walton and Donnell spent a few days during a reconnaissance trip in the overall planning for the project. Cashion, Donnell, Zilhersher, and James H. Brown, Jr., completed the field work in 1950. The map and data were finally prepared by Donnell, Cashion, and Brown, under the general supervision of K. N. Bass. A generalized outline of the Piceance Creek Basin and the location of the mapped areas covered by this and other Oil and Gas Investigations maps are shown on figure 2. Most of the area of the Cathedral Bluffs area is shown on the surface map of Colorado.

The Cathedral Bluffs face westward toward the valley of Douglas Creek and trend generally northward from T. 4 S., R. 100 W., to and beyond the north margin of T. 1 S., R. 100 W. The crest of the bluffs forms the divide between the Douglas Creek and Piceance Creek drainage basins. The area west of the crest is rugged badlands country, with a relief of about 1,000 feet in 3 miles. The area east of the crest of Cathedral Bluffs is a broad plateau that has an average altitude of 8,500 feet and slopes gently eastward toward the axis of the Piceance Creek structural basin, a rolling country containing many straight northeast-trending valleys that are relatively shallow. The maximum relief of most valleys is less than 300 feet, but at some valleys it is about 500 feet. A narrow part of the Roan Plateau trends east across Tps. 4 and 5 S., Rs. 99 and 100 W., in the southern part of the area. The slopes from the plateau are characterized by closely incised canyons.

Most of the oil-shale deposits head in the area, but the normal flow of water is more eastern is south. Douglas Creek and some of its tributaries drain much of the western part of the Cathedral Bluffs area. Tributaries of Piceance Creek drain most of the area east of the crest of the Cathedral Bluffs and south of the eastern part of the Roan Plateau. The south slope of the Roan Plateau is drained by Roan Creek and its tributaries.

Graded and unimproved roads afford access to the Cathedral Bluffs area from East Douglas Creek valley on the west, Piceance Creek valley on the east, and White River valley on the south. The plateau east of Cathedral Bluffs and the Roan Plateau are most easily accessible from Piceance Creek valley. Although a few unimproved roads extend from De Beque to the Roan Plateau, the country between De Beque and the Roan Plateau is so inaccessible from the south by a few dense trails from the gypsum fissus to the plateau.

Large sections of the oil-shale sequence in the Green River formation are closely exposed along the west face of the Cathedral Bluffs and in canyons on the north and south parts of the area; the uppermost part of the sequence is exposed on Black Sulphur Creek in the southwestern part of the area. Most of the oil-shale sequence is buried by younger rocks on the plateau east of the Cathedral Bluffs and in the Roan Plateau, but even the oil-shale sequence lies at a depth of only a few hundred feet.

Seven stratigraphic sections of the interexposed parts of the oil-shale sequence of the Green River formation were measured in detail at least to the nearest 5 to 9 miles apart. These stratigraphic sections are shown on figure 1 and the locations are shown on the geologic map. The correlations of the oil-shale zones and members shown on figure 1 are discussed briefly again working in pace. The oil-shale sequence was chipped core with a pick. Fresh samples of shale were examined carefully in the field and the oil content of each sample was estimated. Composite channel samples of the richest part of the Mahogany ledge were collected at or near each locality and assayed by the Fischer method. Some samples were also assayed. The oil contents of each of these samples are recorded in the chemical laboratory of the U. S. Geological Survey. The assistance and analyses are shown graphically on figure 1.

The geologic boundaries of formations and members were mapped on aerial photographs after the detailed stratigraphic sections were measured. Altitudes of prominent key beds were measured by aneroid barometer at many places throughout the area and by plane table at a few places. On many places throughout the area dips and strikes were measured by determining with the plane table the relative altitudes of three points on each stratum; most of these dip and strike determinations are shown on the geologic map. These data constitute the basis for the contouchstone structure contours shown on the geologic map.

The Cathedral Bluffs area was previously described and mapped as part of the Piceance Creek Basin by Hunt (1936), Bradley (1931), Bradley and Rowland and Day (1934), Kinchester (1937, 1953), and Bradley (1953). Detailed geology of the southern part of the Piceance Creek Basin was described by Duncan and Denson (1948) and Walton, Donnell, and Wright (1951).

STRATIGRAPHY

The rocks exposed in the Cathedral Bluffs area have a thickness of about 4,500 feet. They consist, in ascending order, of interbedded oil shale, shale, and coal of the Mesaverde formation of Late Cretaceous age; interbedded sandstone, variculated shale, and conglomerate of the Wasatch formation of Paleocene and Eocene age; and thin-bedded sandstone, oil shale, shale, sandstone, sedlitic limestone, and algal limestone of the Green River formation of Eocene age (table 1).

Table 1. Generalized description of the rocks exposed in or near the Cathedral Bluffs oil-shale area

System	Series	Formation	Member	Thickness (feet)	Description
Quaternary	Recent	Alluvium		0–50	Gray and brown, fine- to coarse-grained sandstone with interbedded gray mudstone and a few oil-shale beds. Upper part contains lenses of conglomerate. Member weathers to rounded slopes.
Tertiary	Eocene	Green River formation	Parachute Creek member	400 to 750	Grayish-black, gray, and brown mudstone, including many beds of oil shale, and gray and brown siltstone and sandstone key beds. Includes the Mahogany ledge, which includes the Mahogany bed and Mahogany marker. Weathers light gray and forms steep cliffs and stony slopes.
			Garden Gulch member	200 to 300 feet thick.	Lower shaly member (of southern part of the Cathedral Bluffs oil-shale area). Gray mudstone, some gray and brown shale, and a few thin beds of oil shale. Weathers light gray and forms shales and subdued ledges.
			Douglas Creek member	Less than 800 feet thick.	Gray mudstone, a few thin beds of oil shale, and a few thin beds of siltstone and sandstone. Several thin sedlitic and algal beds. Member weathers to form the Douglas Creek arch, Garden Gulch, and lower part of Parachute Creek members. Forms slopes and low cliffs.
		Wasatch formation		800 feet thick.	Massive buff sandstone; a few interbedded red, brownish-yellow, gray, and maroon shale beds. Member forms slope capped by low sandstone cliffs.
	Paleocene	Fort Union formation		Unknown 500 feet exposed in mapped area.	Massive buff sandstone; some shale and coal beds.
Cretaceous	Upper Cretaceous	Mesaverde formation		1,000 feet	Interbedded gray sandstone, siltstone, gray and brown shale, and coal beds. Forms cliffs and slopes.

MESAVERDE FORMATION

The oldest rocks exposed in the Cathedral Bluffs area are those of the Mesaverde formation of Late Cretaceous age. The formation crops out along East Douglas Creek about 3 miles west of the Cathedral Bluffs. The beds dip gently eastward. The Mesaverde formation is composed of massive buff sandstone, some gray shale beds, and a few coal beds. The formation was not examined in detail or mapped during the present investigation. The approximate upper boundary shown on the geologic map is modified from a map by Cole (1950, pl. 18).

WASATCH FORMATION

The Wasatch formation crops out in a relatively broad belt of country in the west-central part of the Cathedral Bluffs area (Cole, 1950, pl. 18; Walton, Geological Survey report on oil-shale resources in Utah, 1951, p. 8), the formation consists chiefly of gray and brown beds that are equivalent to the Fort Union formation, which is of Paleocene age. Paleontological evidence collected by several workers since the publication of this early report has demonstrated that the lowermost part of the formation is of Paleocene age but that most of the formation is of Eocene age (Brown, 1948; Gazin, 1952, p. 1). The Wasatch formation consists of gray, brown and maroon beds, however, is indefinite in the Cathedral Bluffs area (Brown, 1948). Along the upper course of Cathedral Creek the Research formation consists mostly of beds of buff sandstone and small resource of interbedded variculated shale and clay; south of that area the formation contains predominantly of variculated shale, and small amounts of brown sandstone and limestone in lenticular beds.

The Wasatch formation crops out in secs. 21 and 28, T. 1 S., R. 100 W., along upper Spring Creek, and was 371 feet thick there. The contact between the Wasatch formation and the overlying Green River formation was drawn at the top of the uppermost bed of red shale. The contact, however, is somewhat obscure near the head of Cathedral Creek; there it was drawn directly above the uppermost sequence of interbedded thin beds of coal, shale, and redbeds.

GREEN RIVER FORMATION

The Green River formation of Eocene age is divided into four members (Bradley, 1931, p. 9) in the region including the Cathedral Bluffs area, the Parachute Creek member, the Evacuation Creek member, the Garden Gulch member, and the Douglas Creek member. In the southern part of the Cathedral Bluffs area the two lower members and the lowermost part of the Parachute Creek member are chiefly a relatively homogeneous sequence that is not easily separable into members; accordingly, in this part of the area, equivalent rocks of the two members and the lowermost part of the Parachute Creek member are mapped as a single unit, which is designated the Douglas Creek member.

Douglas Creek member.—The Douglas Creek member of the Green River formation consists mostly of massive beds of buff, medium-grained calcareous sandstone, alternating with siltstone and a few beds of fine-grade oil shale. The sandstone is friable and weathers to rounded surfaces, but it forms ledges where it is cemented by calcite. In the part of the Cathedral Bluffs area where the Douglas Creek member was mapped as a single unit, the Douglas Creek member is about 2 miles east of the outcrop of the Lake Creek tuff bed (Bradley and Eugster, 1951, p. 6), and the Lake Creek tuff bed is about 1,000 feet above the base of the Douglas Creek member (Bradley and Eugster, 1951, p. 6). The Douglas Creek member is overlain by tables and bedsitile material. The top of the uppermost massive sandstone bed, which is 10 feet or more thick, was selected as the contact between the Douglas Creek member and the overlying Garden Gulch member. The Douglas Creek member is 800 feet thick in the area where the entire section was not determined. Only the uppermost 50 to 60 feet of the member was measured in detail, in stratigraphic sections 4 and 6 (fig. 1). The Douglas Creek member is about 600 feet thick at the type locality (Bradley, 1931, p. 10) on Douglas Creek, about 6 miles west of the mapped area, but the member thins and the upper sandstones pinch out and intertongue with shale and mudstone eastward and northward from Douglas Creek. The Douglas Creek member is probably about 500 feet thick in the part of the Cathedral Bluffs area, which is the area of the present investigation. In a few miles south of the Cathedral Bluffs area, rocks equivalent to the Douglas Creek member, Garden Gulch member, and the lowermost part of the Parachute Creek member are mapped as a single unit, called the lower shaly member, by Walton (1951). The upper third of the lower shaly member extends in the canyons a few to nearly 10 miles into the southern part of the Cathedral Bluffs area.

Garden Gulch member.—Rocks equivalent to the Douglas Creek member, Garden Gulch member, and the lowermost part of the Parachute Creek member are mainly gray and brown shale and barrowgray mudstone in the southern part of the area, where they are combined into a single unit called the lower shaly member. The member forms steep talus-covered slopes and low cliffs. The Garden Gulch member is 200 to 300 feet thick and about 1,000 feet thick in the De Beque oil-shale area (Baldwin et al., 1951), which adjoins the Cathedral Bluffs area on the southwest.

Parachute Creek member.—The Parachute Creek member of the Green River formation consists of alternating beds of gray, brown, and grayish-black mudstone and oil shale, and contains the oil-shale beds that are of possible economic interest in the mapped area. The member is considered to include the sequence of beds between the top of the uppermost massive sandstone bed of the Douglas Creek arch and the top of the oil-shale unit that forms the gray patches of Big Dark, Corral, and Shell Creeks. The thickness of the member, which was determined by measuring the stratigraphic sections shown in figure 1, ranges from about 400 feet in the southern part of the area to about 750 feet in the northern part (fig. 1, sections 4 and 7). The lower part of the Parachute Creek member thickens and the upper part thins eastward toward the center of the Piceance Creek structural basin.

Several distinctive and persistent beds in the upper oil-shale zone of the Parachute Creek member, most of which are present also in the adjacent De Beque area (Baldwin et al., 1951) and in Parcel Oil Shale Reserves 1 and 3, Garfield County, Colorado (U. S. Geol. Survey Oil and Gas Inv. Ser. Map 94), it is necessary that accurate key beds in the upper part of the Parachute Creek member that were identified in the De Beque area of the Parachute Creek member that were identified in the De Beque area of the Parachute survey 1 and 3 could be traced northward into the Cathedral Bluffs area, because this part of the member is concealed by soil and rubble on gentle slopes. The Mahogany marker, an analcitized tuff that averages 0.5 foot in thickness, is the most persistent key bed that is not composed of oil shale in the area. The bed is 1,000 to 1,100 feet above the top of the thickest oil shale bed in the Green River formation. Beds of tuff are rare in the Mahogany ledge, which contains several beds of distinctive mahogany-colored shale and is the richest oil-shale unit in the area. An analcitized tuff bed, of irregular thickness that ranges from a few inches to 2 feet, is present in all the measured stratigraphic sections 70 to 100 feet above the Mahogany marker in a more limited part of the area; ages 1 foot in thickness and is present in all the measured stratigraphic sections except 1 and 2 (fig. 1). Several zones in the upper part of the Parachute Creek member contain silicified cavities as much as 1 foot long and 3 feet wide in maximum dimensions.

Evacuation Creek member.—The Evacuation Creek member of the Green River formation consists of marlstone, oil shale, and shale that contain a few massive mahogany and gray to grayish-white marlstone, and some beds of low-grade oil shale. The upper part of the member contains lenses of brown massive cross-bedded channel sandstone. Beds of the member comprise the surface rock throughout most of the plateau in the mapped area. The boundary between the Evacuation Creek and Parachute Creek members is drawn between the lowermost beds of massive sandstone above the richest oil-shale beds and the uppermost beds of thin-bedded oil shale and the lowermost sandstone beds are separated from the Mahogany marker of the Parachute Creek member by a sequence of mudstone 300 feet thick. Northward and westward from the area, however, sandstone beds, known as the Evacuation Creek member, occur at progressively lower stratigraphic positions, and the Evacuation Creek member is about 1,000 feet in the southern margin of the mapped area, beds of massive sandstone are present only 75 feet above the Mahogany marker. A complete section of the Evacuation Creek member was not measured in the Cathedral Bluffs area. The thickness was calculated from the geologic map and structure contours to be about 600 feet.

STRUCTURE

The Cathedral Bluffs area is on the west flank of the Piceance Creek structural basin and on the east flank of the Douglas Creek anticline, which are two of the larger structural features in northwestern Colorado. The beds dip generally eastward at an angle of about 2°. Several gentle folds, however, are superimposed on the homocline. The Clear Creek syncline, which is the largest fold in the area, trends N. 10° E. across the Cathedral Bluffs area from the adjacent De Beque oil-shale area to the southeast. North of the Clear Creek syncline and parallel to it is the trifurcation of Cathedral Creek in southwest-trending anticlinal axes containing beds with a maximum dip of 10° on the northeast flank. Another small anticline trends northeastward across the southeastern part of the area; dip of the beds is somewhat less than on Cathedral Creek.

Minor folds ranging in width from a few feet to several hundred feet are present in the sandstone and limestone beds of the Evacuation Creek member. Some of the rich oil-shale beds in the Parachute Creek member contain minor recumbent folds commonly a few feet across.

A fault in beds of the Evacuation Creek member was traced for about 2 miles in secs. 4 and 5, T. 4 S., R. 99 W., and secs. 32 and 33, T. 3 S., R. 99 W. It is about 2 miles farther west than the nearest fault mapped by Cole in the mapped area. A bed of massive sandstone on the downthrown side of the fault trace is in contact with a white weathered bed of mudstone on the northeast side. Neither bed could be identified in the stratigraphic column, so the direction of displacement was not determined. The minimum throw is about 100 feet, which is the thickness of the massive bed on the fault crossers Rose Gulch, 1 mile east of the mapped area.

Two systems of vertical joints, one trending northeast and the other trending northwest, are prominently exposed in the surface rocks. The joints apparently determined the drainage pattern in the mapped area. Most of the joints are vertical, but some are inclined as much as 30°. Joints in outcrops of many of the sedimentary intrusives are northwestward or southeastward, or approximately at right angles to the crossers of the larger streams.

Structure contours drawn on the Mahogany marker are shown on the geologic map. The position of the crossers for much of the area is controlled by altitudes determined in the field along the outcrop of the Mahogany marker and on a relatively few strike and dip readings obtained with the plane table. Structure contours drawn on the Mahogany marker in the vicinity of the crossers in the northeastern part of the mapped area is less reliable than elsewhere, however, because there the altitude of the datum bed was determined by extrapolation from exposed marlstone beds that lie above the Mahogany marker, and the intervals between those beds and the datum bed appear to be variable.

OIL-SHALE ZONES

The principal oil-shale beds of the Cathedral Bluffs area are in the Parachute Creek member of the Green River formation. They are grouped into three oil-shale zones, which are designated the lower oil-shale zone, the middle oil-shale zone, and are separated by commonly barren marlstone ranging from 25 to 65 feet in thickness. These zones, which were recognized in Naval Reserves 1 and 3 (Donnell and Dawson, 1949) and named across the De Beque oil-shale area (Baldwin et al., 1951), are less distinctive in the Cathedral Bluffs area than in the areas to the southeast and southwest in the Cathedral Bluffs area, which are nearer the center of the basin. A few beds of oil shale were measured in the Cathedral Bluffs area, which are correlated with the lower oil-shale zone (fig. 1, sections 5?-7?, at 80 to 100 feet above the Douglas Creek and Garden Gulch members of the Green River formation, but expression of these are poor. During the present investigation detailed studies were confined to the interexposed upper part of the entire sequence of oil-shale beds. Therefore, detailed data are not available for the lower oil-shale zone in the Green River formation, particularly in the southern part of the mapped area.

The upper oil-shale zone is the richest of the three zones. It ranges in thickness from 300 feet in Fletcher Gulch on the northern margin of the area to about 550 feet on Bear Creek in the southern part of the area (fig. 1, sections 1 and 5). The richest part of the upper oil-shale zone, ranges in thickness from about 70 to 275 feet, and contains the richest and thickest sequence of oil-shale beds in the Cathedral Bluffs area. It is generally the richest part of the entire oil-shale sequence in the Piceance Creek Basin.

The middle oil-shale zone ranges in thickness from about 90 feet on the upper part of Cathedral Creek to about 145 feet on Philadelphia Gulch (fig. 1, sections 2 and 6). Correlations of the oil-shale beds in the part of the middle oil-shale zone contains only one sequence of rich oil-shale beds, and that sequence is relatively thin.

The lower oil-shale zone ranges in thickness from a featheredge to about 200 feet in the Cathedral Bluffs area. On Carr Creek, in the southern part of the area, oil-shale beds in the lower oil-shale zone contain the Mahogany bed, marlstone and sandstone. The zone loses its identity northward, and in the northernmost part of the area (fig. 1), in the central part of the area, the lower oil-shale zone is relatively thick and contains richer oil shales than at other outcrops in the area. The richest known sequence of oil shale is as much as 25 feet thick and contained waste averaging 15 gallons per ton.

OIL-SHALE RESOURCES

Preliminary estimates of tonnage and oil content of selected sequences of oil shale in the Cathedral Bluffs area were calculated from field estimates of oil yield of individual beds, examined during the measurement of the stratigraphic sections shown on figure 1, and from laboratory analyses of channel samples collected at most of the localities where sections 1, 3, 4, and 7). Also used were the data of the Cathedral Bluffs and steep slopes in the deep gulches of Big Dark, Corral, and Shell Creeks. The thickness of the member, which was determined by measuring the stratigraphic sections shown in figure 1, ranges from about 400 feet in the southern end western part of the area to about 750 feet in the northeastern part. The part of the Parachute Creek member thickens and the upper part thins eastward toward the center of the Piceance Creek structural basin.

Several distinctive and persistent beds in the upper oil-shale zone of the Parachute Creek member, most of which are present also in the adjacent De Beque area (Baldwin et al., 1951) and in Parcel Oil Shale Reserves 1 and 3, Garfield County, Colorado (U. S. Geol. Survey Oil and Gas Inv. Ser. Map 94), it is necessary that accurate key beds in the upper part of the Parachute Creek member that were identified in the De Beque area of the Parachute survey 1 and 3 could be traced northward into the Cathedral Bluffs area, because this part of the member is concealed by soil and rubble on gentle slopes. The Mahogany marker, an analcitized tuff that averages 0.5 foot in thickness, is the most persistent key bed that is not composed of oil shale in the area. The bed is 1,000 to 1,100 feet above the top of the thickest oil shale bed in the Green River formation. Beds of tuff are rare in the Mahogany ledge, which contains several beds of distinctive mahogany-colored shale and is the richest oil-shale unit in the area. An analcitized tuff bed, of irregular thickness that ranges from a few inches to 2 feet, is present in all the measured stratigraphic sections 70 to 100 feet above the Mahogany marker in a more limited part of the area; ages 1 foot in thickness and is present in all the measured stratigraphic sections except 1 and 2 (fig. 1). Several zones in the upper part of the Parachute Creek member contain silicified cavities as much as 1 foot long and 3 feet wide in maximum dimensions.

Evacuation Creek member.—The Evacuation Creek member of the Green River formation consists of marlstone, oil shale, and shale that contain a few massive mahogany and gray to grayish-white marlstone, and some beds of low-grade oil shale. The upper part of the member contains lenses of brown massive cross-bedded channel sandstone. Beds of the member comprise the surface rock throughout most of the plateau in the mapped area. The boundary between the Evacuation Creek and Parachute Creek members is drawn between the lowermost beds of massive sandstone above the richest oil-shale beds and the uppermost beds of thin-bedded oil shale and the lowermost sandstone beds are separated from the Mahogany marker of the Parachute Creek member by a sequence of mudstone 300 feet thick. Northward and westward from the area, however, sandstone beds, known as the Evacuation Creek member, occur at progressively lower stratigraphic positions, and the Evacuation Creek member is about 1,000 feet in the southern margin of the mapped area, beds of massive sandstone are present only 75 feet above the Mahogany marker. A complete section of the Evacuation Creek member was not measured in the Cathedral Bluffs area. The thickness was calculated from the geologic map and structure contours to be about 600 feet.

Resources of parts of the deposits remote from outcrops or sampled underground were estimated by projecting the data from the outcrops and cores of the middle and upper oil-shale zones into the eastern part of the Cathedral Bluffs area. Estimates of these reserves are based mainly on projections of analyses of core-drill-hole samples obtained in the southeastern part of the De Beque area (Baldwin et al., 1951) and of analyses of cuttings from wells drilled in the Piceance Creek gas field (Donnell and Bolyer, 1950), cuttings from the Cathedral Bluffs area.

Oil-shale resources were estimated for several rich units of oil shale. The part of the Mahogany ledge that includes shale yielding an average of 30 gallons of oil per ton in a continuous sequence 15 feet or more thick is designated as unit 1 in table 2 (see also fig. 3). Most of the oil shale that is estimated to contain slightly less than 7 billion tons of oil shale, capable of yielding slightly less than 5 billion barrels of oil.

The richest part of the Mahogany ledge that yields an average of 25 gallons of oil per ton in a sequence 15 feet or more thick is designated as unit 2 in table 2 (see also fig. 4). It includes the beds of unit 1 and adjacent beds. Unit 2 was estimated to contain about 10.5 billion tons of oil shale, capable of yielding slightly less than 11 billion barrels of oil.

A third category, shown in table 2, was used to show the estimated potential oil yield in the parts of the upper and middle oil-shale zones that contain beds of oil shale that yield an average of 15 gallons of oil per ton 15 feet or more thick. A potential yield of about 16.5 billion barrels of oil was estimated for the upper oil-shale zone and a little more than 2 billion barrels for the middle oil-shale zone; the total potential oil yield was estimated to be about 20.7 billion barrels. Recoverable oil would be less than the amounts tabulated because of losses during mining and retorting.

Oil shale lying along the upper reaches of Clear and Brush Creeks in the southeastern part of the mapped area, along the upper reaches of Black Sulphur and Big Dark Creeks in the southwestern and southeastern parts of the mapped area, and between Lake and Box Elder Creeks near the Cathedral Bluffs appear to be best suited for future exploitation of oil shale. These areas contain the most extensive and richest oil shale in the Cathedral Bluffs area.

REFERENCES

Bradley, W. H., 1929, The varves and climate of the Green River epoch: U. S. Geol. Survey Prof. Paper 158-E, pp. 87-110.

Bradley, W. H., 1931, Origin and microfossils of the oil shale of the Green River formation of Colorado and Utah: U. S. Geol. Survey Prof. Paper 168, 58 pp.

Brown, R. W., 1948, Paleocene deposits of the Rocky Mountains and Plains, U. S. Geol. Survey Profile, map.

Duncan, D. C., and Denson, Oil, 1950, Geology and oil-shale resources of Naval Oil Shale Reserves 1 and 3, Garfield County, Colorado: U. S. Geol. Survey Oil and Gas Inv. Ser. Profile, Map 94.

Gale, H. S., 1910, Coal fields of southwestern Colorado and southeastern Utah: U. S. Geol. Survey Bull. 415, 205 pp.

Gale, H. S., 1910, Coal fields of southwestern Colorado and southeastern Utah: U. S. Geol. Survey Bull. 415, 205 pp.

Hough, J. R., 1940, Sedimentation, October 12.

Pasternova, Bryan, 1939, New Pseudodata and Dinocerata from the Upper Paleocene of western Colorado: Field Mus. Nat. Hist. Pub. 1461, Geol. ser., vol. 6, no. 24, pp. 313-364.

Walton, F. E., Donnell, J. R., and Wright, J. C., 1951, Geology of De Beque oil-shale area, Garfield and Mesa Counties, Colorado: U. S. Geol. Survey Oil and Gas Inv. Ser. OM 114.

Winchester, D. E., 1923, Oil shale in northwestern Colorado and adjacent areas: U. S. Geol. Survey Bull. 741-F, pp. 159-195.

Winchester, D. E., 1925, Oil shale of the Rocky Mountain region: U. S. Geol. Survey Bull. 729, 204 pp.

Wood, H. E., 1941, Problems in the correlation and correlation of the North American Continental Tertiary: Am. Journ. Sci., vol. 32, no. 1, pp. 1-48

Woodruff, E. G., and Day, D. T., 1914, Oil shale of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 501-A, pp. 1-23.

TABLE 2. PRELIMINARY ESTIMATES OF TONNAGE AND POTENTIAL OIL YIELD OF THE RICHEST PARTS OF THE UPPER OIL-SHALE ZONE

	Location T. R.R.	Area (acres)	Average thickness (feet)	Average quantity of rich oil shale per acre (thousands of short tons)	Average oil yield per acre (thousands of bbl. (bbl.=42 gal.))	Quantity of rich oil shale per township (millions of short tons)	Potential oil yield per township (millions of bbl. (bbl.=42 gal.))
Unit 1							
A continuous sequence of oil-shale beds 15 feet or more thick in the Mahogany ledge that yields an average of 30 gallons of oil per ton. (See fig. 3.)	1 S., 99	5,882	17	56.4	56.0	275	182
	2 S., 99	10,000	23	68.3	67.8	1,150	745
	3 S., 99	10,906	23	68.3	68.0	1,320	855
	3 S., 100	1,856	16	47.4	33.8	88	61
	4 S., 99	25,314	33	103.9	74.2	2,111	1,507
	4 S., 100	4,954	17	50.5	36.1	250	179
	5 S., 99	11,762	38	112.8	80.6	2,306	1,648
	5 S., 100	2,432	16	48.0	33.8	192	135
TOTAL	5 S., 99	6,882	24	74.2	50.0	1,511	1,019
		81,180				6,503	4,289
Unit 2							
A continuous sequence of oil-shale beds 15 feet or more thick (Includes unit 1) in the Mahogany ledge and adjacent beds that yields an average of 25 gallons of oil per ton. (See fig. 4.)	1 S., 99	7,074	20	63.6	36.6	491	282
	2 S., 99	25,711	26	79.9	45.6	2,214	1,224
	3 S., 99	22,857	43	119.0	70.8	3,023	1,801
	3 S., 100	2,624	52	98.3	58.7	256	154
	4 S., 99	25,314	63	205.0	118.0	4,065	2,437
	4 S., 100	11,386	50	93.3	54.9	1,051	625
	5 S., 99	11,762	57	173.4	102.4	1,955	1,204