X-ray Mineralogy of the Parachute Creek Member, Green River Formation, in the Northern Piceance Creek Basin, Colorado

GEOLOGICAL SURVEY PROFESSIONAL PAPER 803

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By DONALD A. BROBST *and* JERRY D. TUCKER

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A study of oil shale, marlstone, and tuff, some containing dawsonite, in three exposed sections

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By DONALD A. BROBST and JERRY D. TUCKER

ABSTRACT

Mineralogy of the Parachute Creek Member of the Green River Formation (Eocene age) was studied by X-ray diffraction analysis of about 650 samples of oil shale, marlstone, and intercalated thin-bedded altered tuff collected from three measured sections along the pipeline on the Cathedral Bluffs and along upper and lower Piceance Creek, Rio Blanco County, Colo. The measured sections are described in detail to provide a framework for the discussion of vertical and lateral variation in mineral composition and to provide study sections for stratigraphic and mineralogic correlation of exposed rocks with rocks obtained from drill cores in the deeper parts of the basin.

Mineral composition of the oil shale and marlstone (expressed in relative abundance of the minerals as a function of X-ray peak height) generally is various mixtures of dolomite, calcite, quartz, potassium feldspar, albite, analcime, illite, and pyrite. Dolomite is abundant in most of the rocks. Calcite occurs in more samples and in greater abundance above the Mahogany ledge than below it. Quartz content varies within narrow limits. Potassium feldspar occurs in more samples and in slightly greater abundance than albite. Analcime occurs in most of the rocks but is slightly more abundant in rich oil shale than in marlstone. Small amounts of illitic clay are common. Pyrite is a common accessory mineral that is more abundant in rich oil shale than in lean oil shale and marlstone.

Dawsonite (NaA[illegible]$_2CO_3$), of interest as a potential source of aluminum and, prior to 1966 reported only from beds at depth in the basin, was found disseminated in oil shale exposed below the Mahogany ledge on lower Piceance Creek. The dawsonitic oil shale contains considerably less analcime, dolomite, and calcite, slightly less feldspar, about the same amount of illite, and more quartz than oil shale that does not contain dawsonite. The relations of analcime, dawsonite, and quartz in the exposed rocks suggest that some dawsonite formed diagenetically from analcime. A zone of dawsonitic oil shale about 45 feet thick at its emergence from the subsurface on lower Piceance Creek wedges out about 1.5 miles to the north (shoreward).

Samples of oil shale and marlstone obtained with the use of a dental drill from single laminae and groups of laminae a few millimeters thick indicate a greater vertical variation in the composition than is indicated by composite samples from thicker intervals of the same rock. A unit of oil shale and marlstone about 1 meter thick has laminae containing more dolomite than calcite that alternate with laminae containing more calcite than dolomite. Changes in predominance of dolomite or calcite apparently do not correlate with any obvious feature of the rock.

Tuff beds are abundant; many are less than 1 inch thick, but a few are more than 1 foot thick. The beds weather creamy yellow or orange brown and commonly form reentrants. The major constituents of 74 tuffs studied were analcime, quartz, potassium feldspar, and albite. Less abundant constituents were dolomite, calcite, biotite, and illitic and chloritic clays. Dawsonite was detected in four tuffs along lower Piceance Creek. The abundance of volcanic material delivered to the basin seems to have increased after deposition of the rocks in the Mahogany ledge.

Richly organic carbonate rock, with its small suite of constituent minerals, that forms most of the Parachute Creek Member is considered to be the product of sedimentation and diagenesis in a stratified lake containing fresh (or fresher) water at the top, alkaline water at the bottom, and, at least occasionally, a zone of mixed water in between. The lake waters were carbonated from some decay of the organic matter. Most of the original sediment delivered to the basin yielded its constituents to form authigenic minerals.

INTRODUCTION

Large deposits of oil shale and saline minerals in the Green River Formation in adjacent parts of Colorado, Wyoming, and Utah have drawn much attention since Hayden (1869, p. 90) first described these rocks of Eocene age along the Green River west of Rock Springs, Wyo. Subsequent study has shown that the formation is principally a sequence of complexly related lacustrine deposits that is widely preserved in four basins (fig. 1): the Green River Basin (Bradley, 1964; Culbertson, 1961, 1962, 1965); the Washakie Basin (Roehler, 1969); the Uinta Basin (Bradley, 1931; Cashion, 1967); and the Piceance Creek basin (Bradley, 1931; Donnell, 1961). Oil shale occurs in all the basins but is most abundant and of highest grade in the Piceance Creek basin. Saline deposits vary from basin to basin and include great commercial deposits of trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) in the Green River Basin, Wyo. (Culbertson, 1966; Bradley and Eugster, 1969), and large resources of nahcolite ($NaHCO_3$) and dawsonite ($NaAl(OH)_2CO_3$) in the Piceance Creek basin, Colorado (Hite and Dyni, 1967). Until recently, dawsonite was considered to be a rare mineral (Smith and Milton, 1966); but its discovery in large amounts in the Piceance Creek basin makes it of especial interest as a potential source of aluminum, and research into its origin, occurrence, and distribution has been stimulated.

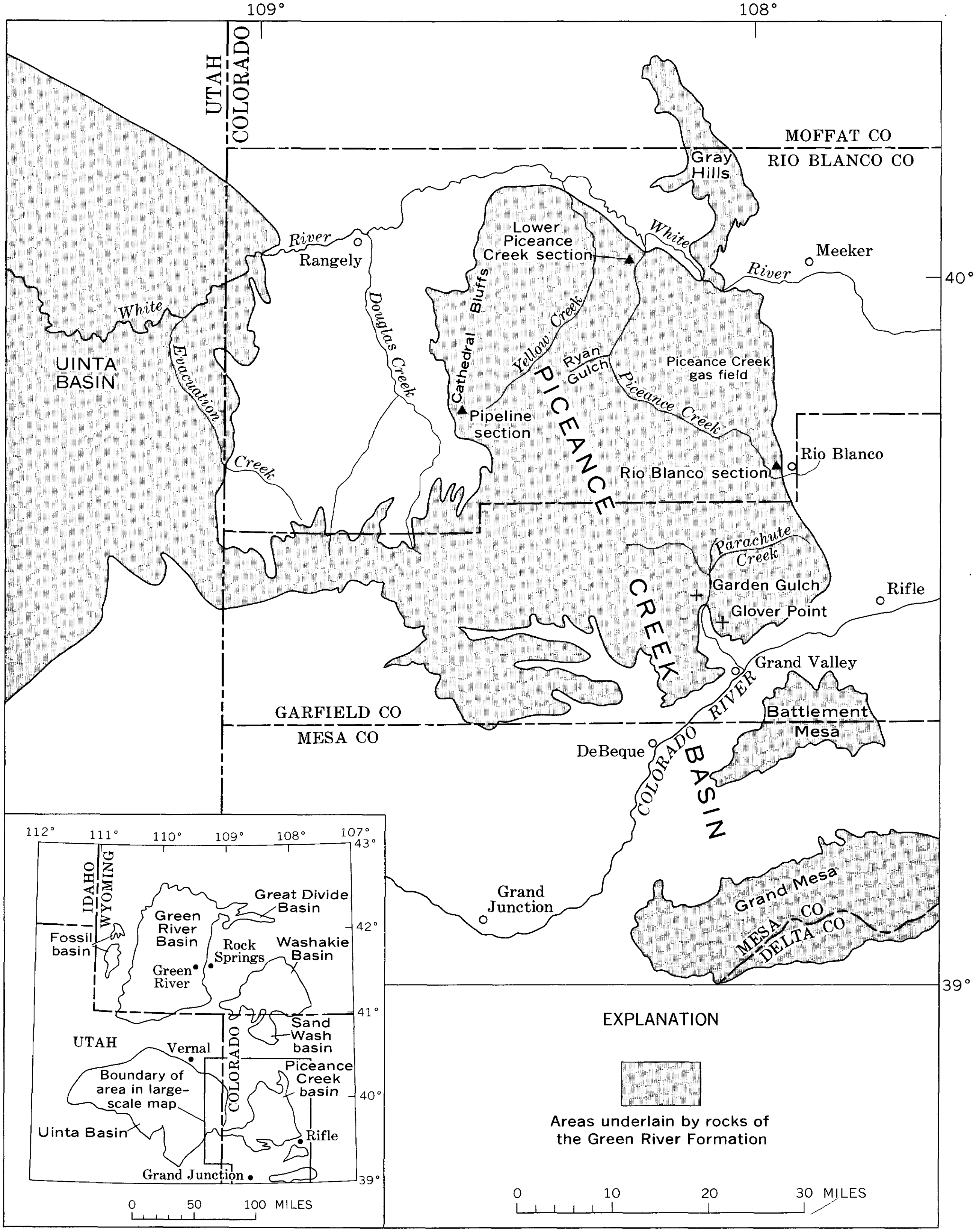


FIGURE 1.—Index map of the Piceance Creek basin and adjacent areas.

This report presents and discusses the data obtained from an X-ray diffraction study of the mineralogy of about 650 samples of rock, chiefly oil shale, marlstone, and altered tuff, collected from exposures of the Parachute Creek Member of the Green River Formation on the periphery of the Piceance Creek basin, Colorado. Vertical and lateral variation of the mineral composition of the rocks is summarized in terms of relative abundance of the various minerals. Dawsonitic rocks, before 1966 known only in drill cores from the deeper parts of the basin, are described from exposures along lower Piceance Creek. This study suggests that dawsonite is a product of the diagenetic alteration of analcime.

Samples examined in this study were collected from three measured sections of the Parachute Creek Member (fig. 1): (1) along the pipeline on Cathedral Bluffs, on the west side of Piceance Creek basin; (2) along lower Piceance Creek, on the north side of the basin; and (3) along upper Piceance Creek west of Rio Blanco, on the east side. The sections are described in detail to provide a framework for the discussion of the X-ray data and to provide study sections for stratigraphic and mineralogic correlation between outcrops and drill cores taken from the interior of the basin. Stratigraphic correlations of units described here with those described by other workers also are suggested.

PICEANCE CREEK BASIN

Piceance Creek basin is a structural basin that lies between the Colorado and White Rivers and is mostly in Garfield and Rio Blanco Counties, northwestern Colorado (fig. 1). The basin forms an extensive, somewhat dissected plateau of about 1,600 square miles that rises to 4,000 feet above the surrounding country. Good exposures of the Green River Formation are common in the steep slopes and cliffs on the periphery of the plateau. The average altitude of the plateau is greater than 7,000 feet, and the highest altitude is 9,400 feet, along the crest of the spectacular cliffs west of Rifle, on the southeast side of the basin. From the rim, the land surface slopes gently downward to the central part of the basin, which is characterized by rolling hills. The vegetation of this semiarid region is sparse and consists mostly of sage, pinion, and juniper. The principal industry is cattle raising; some gas is produced from the Piceance Creek gas field. The nearest commercial centers are Rifle, Grand Junction, Meeker, and Rangely (fig. 1).

LITHOLOGIC TERMS

The lithologic terms discussed below are used in this report to describe the general character of the rocks in the various formations and the more specific character of the beds and groups of beds in the measured sections. The definitions used here closely follow those of Bradley (1931, p. 6–8), who discussed and explained many of the terms that have become a part of the standard vocabulary used to describe the Green River Formation.

Claystone, siltstone, mudstone, and sandstone are all defined by particle size according to the Wentworth scale (Wentworth, 1922). Mudstone has the appearance of a fine-grained rock and contains an indefinite mixture of clay-, silt-, and sand-sized particles.

"Marlstone" is used in the manner of Bradley (1931, p. 7), who designated the term for rocks that consist principally of mixtures of calcite and dolomite and that have textures intermediate between those of mudstone and limestone. In following this European usage, he avoided the need for cumbersome multiword terms and firmly established the term "marlstone" for these lacustrine carbonate rocks.

Claystone, siltstone, mudstone, and marlstone in the Piceance Creek basin generally are massive rocks that are homogeneous in color and texture or, more commonly, are distinctly bedded or laminated. Individual laminae differ in color and thickness but generally are only a few millimeters, or more rarely a few centimeters, thick.

"Shale" categorizes fissile rocks made up of clay-sized particles that weather approximately along bedding planes into thin flakes, chips, plates, and wedge-shaped fragments. The term "shaly" is used to describe mudstone, siltstone, claystone, and marlstone that have incipient fissility that is not developed sufficiently to permit the rock to be called a "shale." "Paper shale" is applied to finely laminated claystone, siltstone, mudstone, and marlstone that tends to part along closely spaced bedding planes. Bradley (1931, p. 7) described paper shales as consisting of very thin laminae of nonfissile rock separated from one another by excessively thin laminae that are fissile.

Oil shale is a special problem. Rocks rich in organic material, commonly called oil shale in the Green River Formation, have long been recognized as being neither oily nor shaly (Bradley, 1931, p. 7, and 1964, p. A19; Donnell, 1961, p. 864; Jaffe, 1962, p. 2; Cashion, 1967, p. 24; Smith, 1969, p. 185). Most of the oil shale is dolomitic marlstone having various amounts of organic matter that was derived chiefly from algae, aquatic organisms, waxy spores, and pollen grains. This organic matter is only slightly soluble in ordinary petroleum solvents, but a large part is convertible to a petroleumlike substance by destructive distillation. The shale part of the term undoubtedly refers to the papery structure observed in many weathered outcrops. (See Bradley, 1931, pl. 4B.)

Discussions in the literature reveal that "oil shale" is a well-established term with economic implications. As early as 1927, the Department of the Interior ruled that any shale that yields oil when distilled will be regarded under the general mining laws as oil shale (Bradley, 1931, p. 7). Standards for the minimum amount of extractable oil to qualify the rock as oil shale have not been set. The term, therefore, has been used more qualitatively than quantitatively.

In the rock descriptions in this report, the term "oil shale" was applied to those marlstones estimated by reason of their color and weight to contain more than 3 gallons of shale oil per ton of rock. Generally the darker the color and the lighter the weight, the higher the oil content. A series of four color modifiers for the overall appearance of the rock was established with the counsel of experienced colleagues and applied on the outcrop to estimate broad ranges of oil content: light brown (lean rock, probably less than 15 gal of shale oil per ton of rock); medium to dark brown (lower and upper values, respectively, of a range of about 15–30 gal of shale oil per ton of rock); and dark red brown (rich rock, probably more than 30 gal of shale oil per ton of rock).

The distinction between the lowest grade of oil shale and "ordinary" marlstone (the barren marlstone indicated by some workers) is a subjective decision. Most marlstones contain some organic matter and probably will yield some shale oil on distillation. According to D. C. Duncan (oral commun., 1970), Fischer assays of some "barren marlstones" indicated the presence of at least 5 gallons of shale oil. Color is not an infallible criterion, but it can be a useful one.

"Tuff" is used to describe any bed that consists largely of volcanic ash, regardless of the degree of alteration. Most of these rocks are analcime rich.

Following the definition of Fahey (1962, p. 18), the adjective "saline" is applied to those minerals that have sodium occupying one or all of the cation positions and that have the carbonate radical supplying all or part of the negative charge.

TERTIARY STRATIGRAPHY

OLDER TERTIARY ROCKS

A structural basin in the Piceance Creek region had formed by early Tertiary time after deposition of the marine and continental rocks of the Cretaceous Mesaverde group (Bradley, 1931; Donnell, 1961). A 5- to 20-foot unit of conglomerate and coarse sandstone of Paleocene(?) age was deposited along the east margin of the basin. This unit has been correlated with the Ohio Creek Conglomerate found in areas to the south (Donnell, 1961, p. 843).

WASATCH FORMATION

The Atwell Gulch Member of the Wasatch Formation conformably overlies the Paleocene(?) conglomerate. This member is a sequence of brown sandstone and somber-colored shale of Paleocene and Eocene(?) age which presumably underlies the entire basin, although it thins from 500 feet on the east side, near Rifle, to a vanishing point on the southwest side (Donnell, 1961, p. 844). The Ohio Creek and the Atwell Gulch were mapped with the overlying Eocene part of the Wasatch Formation by Donnell (1961, p. 844, pl. 48).

The upper part of the Wasatch Formation, of early Eocene age, consists chiefly of fluviatile rocks, including large amounts of clay, shale, and lenticular sandstone accompanied by lesser amounts of limestone, coal, and black carbonaeceous shale (Donnell, 1961, p. 846). Most of the rocks are brightly colored; various shades of red, green, yellow, and purple are common, but dull brown, tan, and gray generally predominate in exposures along the north and west sides of the basin. The maximum exposed thickness, 5,300 feet, is 10 miles northwest of Rifle, and from this point the formation generally thins westward. The base of the unit is indefinite because of a zone transitional with the underlying beds. The contact with the overlying Green River Formation is also transitional.

GREEN RIVER FORMATION

The Green River Formation (Hayden, 1869, p. 90) consists of sandstone, siltstone, shale, and several kinds of carbonate rocks, some of which contain saline minerals and abundant organic matter. Although the original thickness is unknown, at least 3,000 feet of these rocks was deposited in the lacustrine environment that persisted in this area during much of middle Eocene time (Donnell, 1961, p. 847).

In a detailed study of the Green River Formation, Bradley (1931, p. 9) divided the unit in the eastern Uinta Basin, Utah, and the Piceance Creek basin, Colorado, into four members, from bottom to top: the Douglas Creek, Garden Gulch, Parachute Creek, and Evacuation Creek Members. Donnell (1953) proposed the name Anvil Points Member for the eastern equivalents of the Douglas Creek and Garden Gulch Members and part of the Parachute Creek Member exposed on the west side of the basin.

DOUGLAS CREEK MEMBER

The Douglas Creek Member is composed of crossbedded ripple-marked sandstone, algal and ostracodal limestone, oolitic sandstone and limestone, and small amounts of gray shale. Donnell (1961, p. 848–849) reported that the member attains a maximum thickness of 800 feet in the southwestern part of the basin and that it forms a recognizable unit in outcrops on the south and west sides of the basin. Cashion (1969) mapped about 500 feet of the member along Cathedral Bluffs in the Black Cabin Gulch quadrangle (fig. 1, vicinity of the pipeline section). On the south side of the basin, between DeBeque and Grand Valley, the Douglas Creek Member merges laterally with the Anvil Points Member (Donnell, 1961, pl. 48). Duncan and Belser (1950) reported a thin Douglas Creek Member in the subsurface as far northeast as the Piceance Creek gas field. The Douglas Creek Member conformably overlies the Wasatch Formation and is conformably overlain by the Garden Gulch Member.

GARDEN GULCH MEMBER

The Garden Gulch Member contains much papery clayey (illitic) shale and marlstone—generally, though not entirely, barren of oil—as well as thin beds of sandstone, oil-shale breccia, and ostracodal, oolitic, and algal limestone (Donnell, 1961, p. 849). This member crops out in steep slopes between the brown and buff benches of the underlying Douglas Creek Member and the steep white cliffs of the transitionally overlying Parachute Creek Member. The unit is 700 feet thick at its type locality in Garden Gulch (secs. 7 and 8, T. 6 S., R. 96 W.; fig. 1), a small tributary of Parachute Creek on the south side of the basin. A few miles east of the type locality the Garden Gulch Member merges laterally with the Anvil Points Member. Donnell (1961, p. 850 and pl. 48) mapped the member on the west and north sides of the basin to an area along the White River between Yellow and Piceance Creeks, where he, too, found that it apparently merges laterally into the Anvil Points Member.

ANVIL POINTS MEMBER

The Anvil Points Member (Donnell, 1953) is a heterogeneous sequence of gray shale, gray and brown sandstone, siltstone, algal and oolitic limestone, and some marlstone containing little or no oil. The member crops out in cliffs and benches on the east side of the Piceance Creek basin from Parachute Creek on the south to within a few miles west of Piceance Creek on the north (Donnell, 1961, pl. 48). The member does not extend as far basinward as the Piceance Creek gas field. It is considered to be the eastern equivalent of the Douglas Creek and Garden Gulch Members and part of the Parachute Creek Member as exposed on the west side of the basin, and it is probably the equivalent of the delta and shore facies that Bradley (1931, p. 14) described in the Gray Hills, north of the Piceance Creek basin. The Anvil Points Member attains its maximum thickness of 1,870 feet along upper Piceance Creek.

The member interfingers with the underlying Wasatch Formation and the overlying Parachute Creek Member. Donnell (1961, p. 852) chose the top of the Anvil Points Member at "the base of a series of low-grade oil shales and at the top of the uppermost sandstone bed in a sequence of barren marlstone alternating with gray and brown sandstone." The base of the Anvil Points Member is established on a criterion for the top of the Wasatch, that is, at the top of the uppermost red shale bed which is at least 10 feet thick (Donnell, 1961, p. 852).

PARACHUTE CREEK MEMBER

The hallmark of the Parachute Creek Member is oil shale. Bradley (1931, p. 11) noted, "It contains all of the large groups of rich beds, most of the individual rich beds, and a large proportion of the low-grade oil shale." The saline facies as well are most abundant in the Parachute Creek Member. Bradley described the member in detail at its type locality along Parachute Creek, on the south side of the Piceance Creek basin. The member, much of which commonly is exposed in precipitous cliffs, has been mapped all around the periphery of the basin, where it generally is 500 to about 1,000 feet thick. In the subsurface it is thicker; Donnell (1961, p. 852) reported a thickness of 1,700 feet in sec. 31, T. 1 S., R. 96 W.

Bradley (1931, p. 11–13) divided the member at its type locality into three parts—lower oil-shale group, transitional beds, and upper oil-shale group—each of which was defined on characteristics of the included oil shale. Revision of these groups was made at the 1,230-foot-thick section at Glover Point (sec. 22, T. 6 S., R. 96 W.) by Duncan and Denson (1949) and Donnell (1961, p. 854). Donnell and Blair (1970, p. 76) divided the member into a series of rich zones of oil shale (designated R) separated by lean zones (designated L), each zone being numbered from the base of the section. This system of division was found particularly useful on lower Piceance Creek and in the pipeline section.

The richest oil-shale sequence in the member has been called the Mahogany ledge in the surface sections and the Mahogany zone in the subsurface sections. The name is derived from the red-brown mahogany color of the rich oil shales (Bradley, 1931, p. 23). The Mahogany ledge or zone has been traced throughout the basin and locally exceeds 200 feet in thickness. Donnell (1961, p. 856-857), in summarizing the geology of the ledge, reported that the richest oil-shale bed (the Mahogany bed) ranges in thickness from 3 to 10 feet. In the thickest parts of the bed in the deepest parts of the basin the average oil content is 55 gallons per ton of rock. Most of the base of the ledge is marked by a wavy-bedded tuff that attains a maximum thickness of 18 inches. A second characteristic tuff about 2 inches thick lies 8-10 feet higher in the section. An analcimized tuff, generally 3-6 inches thick, that lies 3-14 feet above the Mahogany bed has been called the Mahogany marker. These and several other key beds with informal names are referred to in the descriptions of the measured sections. On some cliffs, the bottom and top of the Mahogany ledge are accentuated by reentrants, or grooves, formed by the more rapid erosion of marlstone that contains only small amounts of organic matter. These grooves have been referred to informally as the A- and B-groove in the upper and lower positions, respectively.

Many cavities are found in the rocks exposed below the Mahogany ledge. The cavities range in largest dimension from a few inches to several feet and presumably were once filled with saline minerals, probably mostly nahcolite.

The Parachute Creek Member is characterized by abundant intercalated beds of tuff which rarely attain a thickness of more than a few inches. Many are less than 1 inch thick, but a few are several feet thick. The thicker beds commonly contain fragments of the enclosing rocks. Most of the tuffs are analcime rich, and they weather yellow or orange brown and commonly form reentrants between marlstone and oil shale in the outcrops. The contacts are smooth to wavy (undulating), and the natures of the upper and lower contacts may differ. Some beds are discontinuous and podlike, but the lateral persistence of many beds is remarkable.

The base of the Parachute Creek Member generally is placed where rocks rich in carbonate (and organic matter) become predominant upward through a transition zone from illitic shale, typical of the Garden Gulch Member, or from the interbedded shales, siltstones, and fine-grained sandstones, typical of the Anvil Points Member.

Bradley (1931, p. 11, pl. 7) placed the top of the Parachute Creek Member at its type locality at the base of a soft limy yellow-brown sandstone. Donnell (1961, p. 857) placed the top of the Parachute Creek Member at the base of the lowest sandstone or siltstone bed 10 feet or more thick that occurs above the uppermost bed of a sequence of designated key beds. In the northern parts of the Piceance Creek basin, beds of brown tuffaceous sandstone unconformably overlie truncated beds of marlstone. Scour channels several feet deep in marlstone were filled with brown sand of the Evacuation Creek Member in some areas along Piceance Creek.

EVACUATION CREEK MEMBER

The Evacuation Creek Member, the uppermost lithologic unit of the Green River Formation, was named by Bradley (1931, p. 14) for about 530 feet of marlstone and some shale and sandy rocks exposed along Evacuation Creek in the eastern Uinta Basin, Utah. In the vicinity of lower Piceance Creek (Rio Blanco County, Colo.), Bradley (1931, pl. 3, loc. 8) assigned at least 500 feet of marlstone and some oil shale and sandy rocks to the Evacuation Creek Member. These rocks, he said, were overlain by about 400 feet of predominantly sandy beds, which he tentatively correlated with the Bridger Formation in the Uinta Basin. In the Piceance Creek basin, Donnell (1961, p. 857 and pl. 48) later mapped the 400 feet of predominantly sandy beds as the Evacuation Creek Member and included the marlstone sequence of Bradley's Evacuation Creek in the Parachute Creek Member (fig. 6). Donnell's usage is followed in this report.

Sandstone abundance increases upward in the section. The sandstones are commonly tuffaceous, massive, brown, and medium to coarse grained. Individual beds cannot be traced very far along the outcrop. These sandstone beds probably formed as stream deposits in the lake basin.

MEASURED SECTIONS

Three excellent exposures of the Parachute Creek Member along the northern periphery of the Piceance Creek basin (fig. 1) were measured in detail; these were the pipeline section along the Cathedral Bluffs, the lower Piceance Creek section, and the Rio Blanco section along upper Piceance Creek. The descriptions include some information on correlations between our work and the work of others in the area of these sections, as well as some possible correlations between our sections. No correlations between sections are expressed or implied by the numbered units of sedimentary rocks and tuff beds or groups of tuff beds, called zones in each of the sections. Numbers were assigned to units consecutively from bottom to top in each section. A comparison of the three measured sections is shown in figure 2.

X-ray data on the mineral composition of the rocks collected from the measured sections are shown in tables and figures and are discussed in later parts of this report. Sampled units in the measured sections are designated by an asterisk, and samples in the tables and figures are correspondingly numbered for the units from which they came.

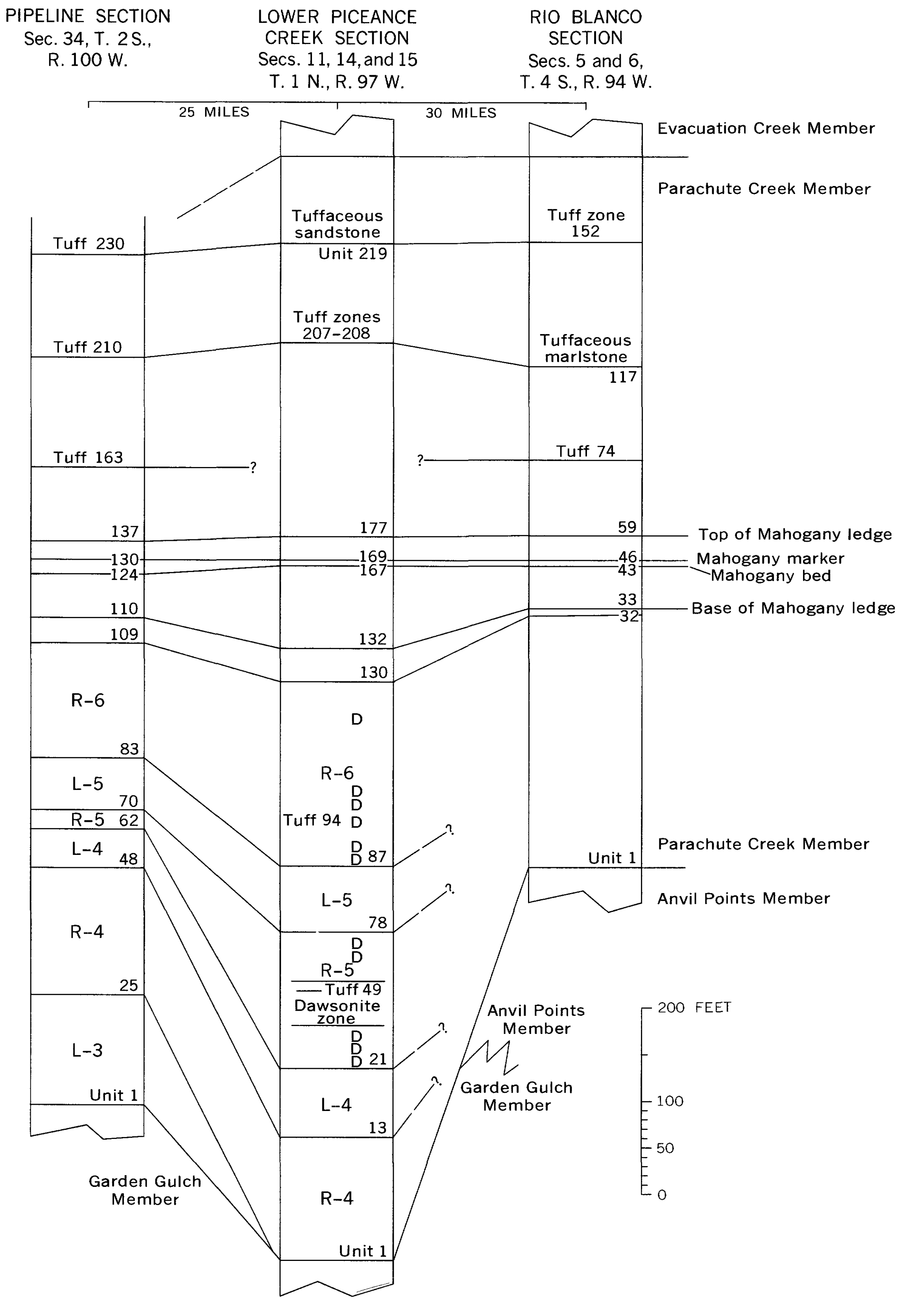


FIGURE 2.—Correlation of three measured sections of the Parachute Creek Member of the Green River Formation in the Piceance Creek basin. Numbered units refer to units described in each measured section. D indicates occurrence of dawsonite. Numbers prefixed by R and L refer to zones rich or lean in oil shale, as applied

PIPELINE SECTION

A nearly complete 909-foot-thick section of the Parachute Creek Member was measured along a bulldozed pipeline right-of-way up the west face of the Cathedral Bluffs near the center of sec. 34, T. 2 S., R. 100 W., Rio Blanco County, Colo. The geology of this area in the Black Cabin Gulch (7½-min) quadrangle was mapped by Cashion (1969). A lithologic section accompanied by a histogram showing Fischer assays of oil content was compiled by Trudell, Beard, and Smith (1970, fig. 5).

Access to the pipeline section from the west is by the paved Douglas Pass road and its subsidiary unpaved roads shown on the 7½-minute White Coyote Draw and Black Cabin Gulch quadrangles. From the east, the top of the section is reached by about 20 miles of unpaved access road beginning at the junction of the Ryan Gulch and Piceance Creek roads and shown on the 7½-minute Square-S, Wolf Ridge, Yankee Gulch, and Black Cabin Gulch quadrangles. Use of four-wheel-drive vehicles is necessary for access from the west and is recommended for access from the east.

The lower contact of the Parachute Creek Member is gradational but is placed where the illitic clay shale of the underlying Garden Gulch Member gives way upward to the predominant marlstone of the Parachute Creek. The contact of the Parachute Creek with the overlying Evacuation Creek Member is not exposed but probably lies in the rounded slopes within about 25 feet of the top of the measured section.

The lithic details of the section are given below, and the mineral composition of 71 samples from the section is shown in table 4.

Nearly complete section of the Parachute Creek Member of the Green River Formation along the pipeline in the center of sec. 34, T. 2 S., R. 100 W., Rio Blanco County, Colo.

[Section measured by D. A. Brobst, J. D. Tucker, and J. R. Dyni. * indicates sample data in table 4]

	Thickness (feet)
Top of exposed section.	
Parachute Creek Member (part):	
*230. Tuff, analcimic and feldspathic; weathers yellow brown. (Yellow T 88 painted on face of outcrop below the tuff.)	1.7
229. Marlstone, light-brown, and some light-brown oil shale	22.0
*228. Tuff, analcimic	.2
227. Oil shale, laminated, medium- to dark-brown	5.3
*226. Oil shale, dark-red-brown, pyritic; weathers blue gray	1.3
225. Oil shale; mostly light to medium brown	15.2
*224. Oil shale, dark-red-brown, pyritic; weathers blue gray	1.0
223. Oil shale, medium- to light-brown	10.5

Nearly complete section of the Parachute Creek Member of the Green River Formation along the pipeline—Continued

Parachute Creek Member (part)—Continued

	Thickness (feet)
222. Tuff, analcimic, weathers light yellow orange	0.1
221. Oil shale; mostly medium to dark red brown. Samples 1–10, collected at 20-ft lateral intervals from a bed 3.1 ft below top of unit, were studied in detail (fig. 16)	11.7
220. Marlstone, light-brown	1.6
219. Oil shale, medium- to dark-brown	1.6
*218. Oil shale, medium-brown. Sample is from 2.6 ft above base. Samples from 96.8-cm-thick sequence from lower part of unit were studied in detail (table 8)	10.6
217. Oil shale, medium- to dark-brown, with tuff zone consisting of 6 thin, discontinuous, poddy analcimic tuffs. (Yellow T 85 painted below uppermost tuff of zone.)	4.9
216. Tuff; discontinuous pods; weathers dark rusty brown	.1
215. Oil shale, light-brown, and interbedded marlstone	4.6
214. Oil shale, dark-red-brown, pyritic	.6
213. Oil shale, light- to medium-brown; laminated beds. Contained remains of turtle tentatively identified as a species of *Echmatemys* by G. Edward Lewis (written commun., 1967)	9.5
212. Tuff, analcimic; pods and undulating bed; weathers rusty brown	.1
*211. Oil shale, dark-red-brown, laminated, pyritic; weathers blue gray	2.1
210. Oil shale, medium-brown; contains 4 thin rusty brown tuffs	3.9
209. Tuff; relatively continuous bed ¼ in. thick and discontinuous pods as much as 2 in. thick and 3 in. long	.1
208. Oil shale, medium- to dark-brown. (Yellow streak painted on dark-brown bed about 3 ft above base.)	8.5
207. Tuff	.02
206. Oil shale, medium-brown	.3
205. Tuff	.01
204. Oil shale, medium-brown	.2
203. Tuff	.02
202. Oil shale, dark-brown	1.5
201. Tuff, dark-rust-brown	.1
200. Oil shale; mostly medium brown; some light brown	7.4
199. Tuff; mostly continuous undulating bed with some pods as much as 1 in. thick	.1
*198. Oil shale, dark-brown, pyritic; weathers blue gray	3.0
197. Oil shale, light-brown, and some light-brown marlstone. Samples 350–364, from a 12.15-cm-thick sequence, are fossiliferous rock studied in detail (figs. 9, 10)	6.2
196. Oil shale, medium- to dark-brown	2.4
*195. Oil shale, light- to medium-brown. Continuous zone of fossil insects—many similar to those described by Bradley (1931, p.49–51, pls. 26–28)—begins here and extends upward for about 40 ft. Sample is light-brown oil shale. Base is 158 ft above top of Mahogany ledge and is correlated with unit 155 ft above Mahogany	

Nearly complete section of the Parachute Creek Member of the Green River Formation along the pipeline—Continued

Parachute Creek Member (part)—Continued

	Thickness (feet)
ledge (Bradley, 1931, pl. 8). (Yellow BG painted on outcrop 10.5 ft above base.)	13.0
194. Oil shale, medium- to dark-brown, pyritic	1.6
193. Oil shale, light-brown, with tuff pods near top and base of unit	3.7
192 Oil shale, medium-brown	6.4
191. Oil shale, dark-brown, pyritic	1.2
190. Oil shale, light-brown, and marlstone; weathers conchoidally	7.8
189. Oil shale, dark-brown; weathers to blue plates	2.3
188. Oil shale, light-brown, and light-brown marlstone	6.7
*187. Tuff, analcimic; weathers rusty brown inside and white outside	.1
*186 Oil shale, dark-brown. (Yellow 13 painted below the bed.)	1.3
185. Marlstone, light-brown, soft, tuffaceous(?)	6.6
184. Marlstone, light-brown	.9
183. Tuff, light-brown, analcimic; weathers blocky	.2
182. Marlstone, light-brown	6.5
181. Tuff, analcimic, light-pink-brown; weathers light orange; undulating base with some inclusions of oil shale	1.7
180. Oil shale, medium-brown	1.2
179. Tuff, weathered; ½ in. thick	.05
178. Marlstone	.2
177. Tuff, analcimic, light-pink-brown; weathers light orange	.5
176. Marlstone, light-brown	.2
175. Tuff	.2
174. Marlstone, light-brown	.4
173. Tuff, analcimic; weathers rusty brown	.4
172. Marlstone, light-brown to yellow	3.5
171. Oil shale, medium- to dark-brown; weathers platy; lower 3 in. contains 2 tuffs, each about 1 in. thick	1.5
170. Oil shale, light-brown, and light-yellow marlstone	6.5
169. Oil shale, medium- to dark-brown	1.2
168. Oil shale, light-brown, and light-brown marlstone	5.0
167. Tuff, analcimic; weathers rusty brown	.6
166. Oil shale, light-brown	.6
165. Tuff, analcimic; white smooth top; undulating base; weathers light orange brown	2.2
164. Oil shale; light brown near base to dark brown near top	2.0
*163. Tuff zone. Two tuffs split by 6 in. of light-brown marlstone. Sample is from upper part of upper bed. About 82 ft above Mahogany ledge. Possibly correlates with tuff of unit 74 in Rio Blanco section	2.4
*162. Oil shale, light-brown to dark-red-brown; dark shale weathers blue gray. Sample is from dark-red-brown zone near base	4.8
161. Tuff, analcimic	.5
160. Oil shale, dark-brown; upper 1 foot has irregularly scattered pods of tuff 6 in. thick and as much as 2 ft long	3.4
159. Tuff zone, Three thin tuffs (in light-brown oil shale): at base, 8 in. above base, and at top	1.0
158. Oil shale, light-brown, and yellow marlstone	6.9
157. Tuff, analcimic, white; weathers rust brown. (Yellow T 62 painted above bed.)	.2
156. Oil shale, medium- to dark-brown; includes a zone of tuff pods ¼ in. thick 2.3 ft above base and 2 red-brown tuff beds 1 in. thick at 5.3 and 5.5 ft above the base	5.5
155. Tuff, analcimic; weathers rust brown	.1
154. Marlstone, yellow, silty	1.0
153. Tuff, analcimic; ¼ in. thick	8.5
152. Marlstone, yellow, silty	1.0
151. Oil shale, light-brown; some carbonate pods ½ in. thick and a few inches long	8.5
*150. Tuff, analcimic, dark-brown; weathers light brown; sharp even contact at top; undulating basal contact with relief of 2–3 in. Contains many thin stringers of marlstone	2.5
149 Oil shale, dark-red-brown	1.7
148. Tuff, analcimic, white; thickness varies from 0.2 to 0.4 ft; weathers blocky. (Yellow T 57 painted on outcrop above tuff.)	.3
*147. Oil shale; mostly dark red brown; some light brown. Sample is dark-red-brown oil shale. Contained a catfish skull of *Ameriurus, Rhineastes,* or *Pimelodus,* as identified by D. H. Dunkle (written commun., 1967)	5.1
*146. Tuff, analcimic; weathers light orange; persistent bed, undulating contacts 0.4–1 ft thick	.5
145. Oil shale, dark-red-brown	1.7
144. Oil shale, light-brown, and some light-brown marlstone; laminated	4.7
143. Tuff; undulating contacts	.02
*142. Oil shale, medium-brown, laminated. Sample is from 2 ft above base	2.6
141. Marlstone, light-brown; upper part contains small pods of calcite. Zone of tuff pods 3 in. long and ¼ in. thick 2.9 ft above base	4.1
*140. Oil shale, medium-brown. Sample is from 2.4 ft above base. (Yellow 11A3 painted on outcrop.)	2.7
139. Oil shale, light-brown, and marlstone. 1.5 ft above base is 2.2-ft-thick zone of tuff consisting of 6 discontinuous layers of tuff pods 1 in. across and ¼ in. thick that is interbedded with oil shale	6.7
138. Oil shale, dark-brown, and 3 thin tuffs at 1.2, 1.5, and 1.9 ft above base	1.9
*137. Marlstone, light brown. Marlstone sample is from 10.6 ft above base. 8.6 ft above base is zone 1.2 ft thick that contains pods of siliceous material. Probable position of the A-groove	14.8
136. Oil shale, dark-brown; weathers blocky and blue gray. Contains 10 thin beds of tuff in lower 4 ft. Sample is oil shale at top of unit. Top of the Mahogany ledge. (Yellow 10 painted on outcrop.)	9.1
135. Oil shale, dark-brown; fissile in lowermost 0.5 ft; weathers blue gray	2.0
134. Tuff	.25
133. Oil shale, dark-brown; weathers blue gray	1.5
132. Tuff; thin bed with undulating contacts	.1

Nearly complete section of the Parachute Creek Member of the Green River Formation along the pipeline—Continued

Parachute Creek Member (part)—Continued

Unit	*Thickness (feet)*
131. Oil shale, dark-brown	7.0
*130. Tuff, gray, evenly bedded. The Mahogany marker	.5
129. Oil shale, medium- to light-brown. 3.8 ft above base is 0.3 ft of contorted papery shale	8.5
128. Tuff, analcimic; persistent bed 0.1–0.4 ft thick with smooth top and undulating base	.2
127. Oil shale, dark-red-brown	.95
126. Tuff	.05
125. Oil shale, dark-red-brown	1.8
*124. Oil shale, very dark red brown. The Mahogany bed	1.9
123. Oil shale, medium- to dark-red-brown	2.0
122. Tuff, analcimic, brown; even contacts; persistent	.1
121. Oil shale, light- to dark-brown	10.3
120. Tuff	.05
119. Oil shale, light- to dark-brown; weathers blue gray	3.2
118. Tuff zone. Four tuffs; persistent beds ¼–½ in. thick, separated by ½–1 in. of oil shale. (Yellow horizontal line painted on outcrop.)	.4
*117. Oil shale, medium- to dark-red-brown; weathers blue gray. Sample is medium-brown oil shale 5.8 ft above base	13.8
116. Tuff, analcimic; wavy contacts	.1
115. Oil shale; contains thin tuff in upper 0.5 ft	3.7
114. Tuff, analcimic; ½ in. thick; persistent bed	.05
113. Oil shale	1.1
112. Tuff, analcimic, laterally persistent; smooth contacts	.3
*111. Oil shale, medium- to dark-brown. Sample is dark brown	10.9
*110. Tuff, analcimic, light-yellow-gray; fragmental appearance; very fine grained. Base of the Mahogany ledge	2.1
*109. Marlstone, gray-orange, laminated, soft; weathers to slabby fragments; slope former; some interbedded oil shale. At 17.4 ft above base, cavities 1 ft in diameter along a persistent zone possibly mark a saline zone. At 25 ft above base is tuff 0.1–0.4 ft thick, lenticular. Sample is medium-brown oil shale 17.4 ft above base. Position of the B-groove	26.5
*108. Oil shale, burned (?), soft, punky, crumbly. Top of R–6 zone	4.0
107. Tuff, analcimic, pink	.15
106. Oil shale	.5
105. Tuff, analcimic; weathers reddish; wavy base; smooth upper contact	.15
104. Oil shale	1.7
103. Tuff; weathers red brown; even contacts. (Painted yellow 36 on outcrop.)	.25
102. Oil shale	4.3
101. Tuff; irregular contacts; poorly exposed	.2
100. Oil shale, light-brown; weathers to fissile plates	2.4
99. Oil shale; upper 0.5 ft contains cavities caused by leached saline minerals(?)	1.5
98. Tuff	.05
97. Oil shale, light-brown; weathers to fissile plates	1.2
*96. Tuff, analcimic; persistent bed, regular contacts.	.05

Nearly Complete section of the Parachute Creek Member of the Green River Formation along the pipeline—Continued

Parachute Creek Member (part)—Continued

Unit	*Thickness (feet)*
95. Oil shale, light-brown, fissile	2.7
94. Tuff; irregular contacts	.15
93. Oil shale, gray-brown, platy	7.5
*92. Tuff, analcimic; weathers bright pink; persistent bed; smooth contacts	.5
91. Oil shale, gray-brown, fissile	5.5
90. Tuff; weathers yellow	.6
89. Oil shale, dark-brown; weathers light yellow brown, fissile to platy	10.9
88. Tuff, analcimic; weathers reddish brown. (Black T 29 painted on outcrop.)	.06
*87. Oil shale, light- to dark-brown; weathers soft; platy to subfissile. Sample is medium-brown oil shale 26.5 ft above base	33.8
*86. Tuff analcimic; weathers red brown; persistent; smooth contacts	.2
85. Oil shale. Lowermost 10 in. extremely weathered and contorted, possibly marks a saline zone. (Yellow 9 painted on slab of rock.)	8.1
*84. Oil shale, light-brown, marlstone. Partly concealed. Some blue-gray-weathering oil shales 2–4 in. thick. (At 21.2 ft above base is black 44 painted on rock.) Sample is light-brown oil shale 19 ft above base	39.3
83. Oil shale, with cavities as much as 0.4 ft in diameter. Laterally persistent. Base of R–6 zone	1.0
82. Marlstone, light-brown. Top of L–5 zone	1.0
81. Tuff	.05
80. Marlstone, light-brown; has cavities 3.0 ft above base	8.3
79. Marlstone, light-brown; contains cavities and contorted beds, probably a solution breccia	1.5
78. Tuff, light-gray; laterally persistent bed	.1
*77. Marlstone, light-brown, tuffaceous	3.7
*76. Marlstone, light-orange-brown; brecciated bed; laterally continuous; many crystal cavities; honeycomb structures. Sample is brecciated marlstone	.7
75. Marlstone, light-brown; weathers to brittle slabs	8.7
74. Oil shale, light-brown; weathers platy; solution cavities as much as 1 ft in diameter are irregularly distributed through unit	2.0
*73. Marlstone, light-brown; weathers yellow, slabby. Sample is from 0.5 ft above base	16.4
*72. Tuff, feldspathic, fine-grained; a distinctive white	.3
71. Marlstone weathers light yellow orange; slabby; some light-brown oil shale. Several small cavities from leached saline (?) minerals at 10.1 ft above base. Partly covered	12.4
70. Tuff. Base of L–5 zone	.1
69. Oil shale, light-brown; weathers blocky. (This unit near a green and white metal fence post and a wooden stake is marked ¼ on the pipeline right-of-way.) Top of R–5 zone	4.0
68. Oil shale, medium- to dark-brown; weathers blue gray; top is a sharp break with overlying unit. Cavities 6-10 in. in maximum dimension caused by leached saline minerals; broken paper-thin brown septa	2.4
67. Oil shale, light-brown; weathers blocky	5.3

Nearly complete section of the Parachute Creek Member of the Green River Formation along the pipeline—Continued

Parachute Creek Member (part)—Continued

	Thickness (feet)
66. Tuff	0.1
65. Oil shale	1.0
64. Tuff	.1
*63. Oil shale, dark-brown; weathers blue gray; Brecciated. Cavities to 6 in. in maximum dimension caused by leached saline minerals. Heavy films of hydrocarbon material along bedding planes. Samples are dolomitic septum from cavity and dark-brown oil shale	1.0
62. Oil shale. Base of R–5 zone	5.1
*61 Tuff, feldspathic; smooth contacts top and base; laterally persistent. Top of L–4 zone	.1
60. Marlstone, light-brown; weathers yellow	2.4
59. Oil shale, light-brown	7.0
58. Tuff zone. Five tuffs ¼–½ in. thick with small inclusions of oil shale. Tuffs interbedded with oil shale	1.8
*57. Oil shale, light-yellow-brown to light-brown-gray; weathers platy and blocky in alternate layers. Sample is from 1 ft below top	8.9
56. Tuff, analcimic; laterally persistent; undulating upper contact; basal contact irregular; interfingers with underlying oil shale	.15
55. Oil shale, light-yellow-brown to light-brown-gray; weathers platy and blocky in alternate layers	8.8
*54. Tuff, analcimic; laterally persistent; undulating contacts	.3
53. Marlstone, light-brown-gray; weathers platy to blocky	3.5
52. Tuff	.02
51. Marlstone	.6
50. Tuff	.04
49. Marlstone, light-brown-gray; weathers slabby to blocky	5.9
*48. Tuff, analcimic; weathers orange brown; sandy textured; lower contact smooth, upper contact undulating. Base of L–4 zone	.2
47. Oil shale, light-brown; weathers slabby. Top of R–4 zone	2.8
*46. Oil shale, dark-brown to red-brown; weathers blue gray. Locally, beds are contorted and have secondary coatings and pods of dolomite. Possibly marks a zone leached of saline minerals. Sample is dark-brown oil shale. (Near top of unit is black 340 painted on outcrop.)	1.2
45. Marlstone, gray; hackly fracture	6.2
*44. Tuff, analcimic; weathers bright orange; laterally continuous bed	.1
*43. Oil shale, light-brown, and some alternate layers of dark-brown oil shale a few inches thick. Scattered gar-pike scales. Dark beds weather blue gray. Unit weathers blocky in lower part, platy in upper part. Several thin tuffs less than ¼ in. thick in upper 1.5 ft. Sample is interlayered light- and dark-brown oil shale from uppermost 1 ft. (Black 360 painted on rock 3 ft above base.)	13.6
*42. Tuff zone. Uppermost tuff is 0.1 ft thick, analcimic; has wavy lower contact, smooth upper contact. Lower 0.4 ft of unit contains 3 tuff beds 1/16–⅛ in. thick about ½ in. apart separated by dark-brown oil shale. (Yellow square painted on outcrop above tuff zone, and yellow T–13 painted on outcrop face 3 ft above tuff zone.)	0.5
41. Oil shale, medium- to dark-brown; weathers mostly blue gray. Some gar-pike scales	9.7
*40. Tuff zone. Uppermost 0.6 ft consists of tuff (75 percent) and many platy inclusions of oil shale (25 percent). Upper and lower contacts smooth. Light-brown blocky-weathering oil shale 0.8 ft thick above lowermost tuff and ¼ in. thick at base of unit. Sample is lowermost tuff, dolomitic	1.42
*39. Oil shale, medium- to dark-brown; weathers blue gray. Contains pods of dolomite that weather light brown. Sample is medium-brown oil shale from base of unit	3.5
38. Oil shale, light- to medium-brown, and some gray marlstone	11.8
*37. Tuff, analcimic, evenly bedded; smooth contacts at top and bottom	.15
36. Oil shale	2.6
35. Tuff zone. Two tuffs. Lower is ⅜ in. thick, upper is ⅛ in. thick; separated by ¼ in. light-brown oil shale	.06
*34. Oil shale; weathers gray; conchoidal fracture; dark specks of organic matter. Sample is from 1 ft above base	5.0
*33. Tuff, analcimic; weathers yellow; fine-grained; undulating contacts. Intertongues with enclosing oil shale. (Yellow T 9 painted on outcrop.)	1.2
32. Oil shale	3.0
*31. Tuff, analcimic. (Yellow circle painted on outcrop.)	.08
30. Oil shale	17.7
*29. Tuff, analcimic, lenticular; discontinuous pods as much as 1 in. thick	.08
*28. Oil shale, light- to medium-brown; contains disseminated nodules of dolomite as much as 1 in. in diameter. Some beds of light-gray-brown marlstone 0.1–2 ft thick. Sample is light-brown oil shale 26.8 ft above base	28.0
*27. Oil shale, light-brown; weathers blocky; contains 5–6 in. long and 3–4 in. thick of dolomite that weathers white. Sample is from dolomitic pod. (Black 450 painted at base of unit.)	3.5
26. Oil shale, dark-brown; weathers blue gray	1.0
*25. Oil shale, light- to medium-brown, fissile, and blocky marlstone. Contact with overlying unit is sharp. Sample is medium-brown oil shale 4 ft above base. Base of R–4 zone	23.7
24. Marlstone, medium-brown; weathers blocky; contains flakes of carbonaceous matter and pods with iron-stained rims. Top of L–3 zone.	3.5
23. Oil shale, gray-brown, fissile. Top 1 in. is ostracodal dolomite	3.6
*22. Marlstone, light-brown. Intraformational conglomerate at base contains broken, flat, angular fragments of carbonate rock. About 0.4	

Nearly complete section of the Parachute Creek Member of the Green River Formation along the pipeline—Continued

Parachute Creek Member (part)—Continued	*Thickness (feet)*
ft above is massive bed of marlstone with stringers and clusters of pyrite perpendicular to bed. Above the pyritic part of unit are thin pods of dolomite parallel to beds. Sample is pyritic marlstone	1.6
21. Marlstone, light-brown	4.9
*20. Oil shale, light-brown; weathers gray; contains lenticular tuffaceous marlstone as much as 1 in. thick. Marlstone sampled at 8.3 ft above base	17.1
19. Marlstone, medium- to dark-brown	.7
*18. Marlstone, tuffaceous ½–1 in. thick	.08
17. Marlstone, light-yellow-brown, laminated; weathers white. (2.5 ft below top is black 510 painted on outcrop.)	11.5
16. Oil shale, medium-brown, fissile. Middle of unit contains tuff zone 4, consisting of 3 tuffs ¼ in. thick	2.6
15. Marlstone, yellow-brown; weathers white; blocky	7.5
*14. Marlstone, light-brown; weathers gray; conchoidal fracture; disseminated specks of limonite. Samples from top of unit and 0.6 ft above base are distinctive 1-in. and ¼-in. dolomite-rich beds that resemble tuffs	1.2
*13. Tuff, analcimic	.04
*12. Marlstone, light-brown; weathers gray; conchoidal fracture	8.8
11. Marlstone, light-brown; weathers white; blocky	5.8
10. Marlstone, light-brown; light-gray band in middle	.2
*9. Marlstone, light-brown, blocky	5.3
8. Marlstone, light-brown, fissile	1.0
7. Marlstone, light-yellow-brown, well-laminated, blocky	7.5
*6. Oil shale, brown; black specks of carbon. Some yellow beds of dolomite 1 in. thick at 3 ft and 6 ft above base. First significant oil shale in section. Sample is oil shale about 3 ft above base. (Yellow circle painted on outcrop at base of unit.)	6.9
*5. Marlstone, green, dolomitic, dense; conchoidal fracture	5.5
4. Marlstone, light-brown; weathers white; blocky; resistant	3.6
3. Shale, dark-yellow-olive, fissile to subfissile	4.5
*2. Marlstone, light-yellow-brown; weathers white; blocky. (Yellow circle painted at base of unit.)	9.3
*1. Marlstone, dolomitic, light-green-gray. Contains fish teeth. Base of good exposures and designated base of Parachute Creek Member	1.0
Incomplete thickness of Parachute Creek Member (rounded)	909

Garden Gulch Member (part):	*Thickness (feet)*
*Shale and siltstone, poorly exposed; mostly light yellow brown to dark brown; conchoidal fracture common. Weathers to lighter brown fragments. Shales weather to small soft fragments easily crushed by hand. Illitic clay abundant. Some calcite and (or) dolomite common, especially near top; these carbonate beds increase in abundance upward and mark a transition to rocks of the overlying member. Sample of brown silty shale, taken about 60 ft below top of unit, is considered representative of many beds in the upper part of the member. (Base of unit is in the cut bank along pipeline right-of-way about 200 ft uphill from intersection of access road and pipeline. Yellow 1 painted on trunk of pine tree just above cut bank.)	90.0
Incomplete thickness of Garden Gulch Member	90.0

LOWER PICEANCE CREEK SECTION

A complete section of the Parachute Creek Member (1,185 ft) is exposed in the cliffs along lower Piceance Creek in sections 11, 14, and 15, T. 1 N., R. 97 W., Rio Blanco County, Colo. The area lies in parts of the White River City and Barcus Creek SE 7½-minute quadrangles.

The base of the section is on the hill west of Piceance Creek road 2.4 miles south of its junction with Colorado Highway 64. Locations of the parts of the section are shown in figure 3.

The base of the section is not well exposed but lies in a transition zone between the predominantly clay (illitic) shales of the Garden Gulch Member below and the carbonate-rich rocks of the Parachute Creek Member above. The contact, placed where carbonate-rich rocks become the predominant rock type, is shown in figure 4. The top of the section has good exposures of the upper part of the Parachute Creek Member and the lower part of the overlying sandy beds of the Evacuation Creek Member (fig. 5).

The mineral composition of 135 samples from this section is given in table 5 and is discussed in detail later. Rocks in this section are of especial interest because they contain dawsonite. The lithic details of this section follow.

Complete section of the Parachute Creek Member of the Green River Formation along lower Piceance Creek in secs. 11,14, and 15, T. 1 N., R. 97 W., Rio Blanco County, Colo.

[Section measured by D. A. Brobst and J. D. Tucker with assistance of J. R. Dyni in 1966 and collaboration of G. N. Pipiringos in 1970. * indicates sample data in table 5]

Evacuation Creek Member (part):	*Thickness (feet)*
*Sandstone, tuffaceous, brown, fine to very fine grained; lower contact unconformable. Base of member (fig. 5). Two samples. (Yellow E painted on rock at base of unit.)	Unmeasured
Parachute Creek Member :	
233. Marlstone, light-brown; weathers slabby and platy	5.0
*232. Oil shale, dark-red-brown, pyritic	.3

Complete section of the Parachute Creek Member of the Green River Formation along lower Piceance Creek—Continued

Parachute Creek Member—Continued

	Thickness (feet)
231. Marlstone, light-brown; weathers slabby and platy. Partly covered	12.0
*230. Oil shale, dark-red-brown, pyritic; weathers blue gray and platy. Two samples	.8
229. Marlstone, light-brown; weathers platy and slabby; forms ledges along the hill slopes	9.0
*228. Oil shales; mostly light brown; some medium brown	12.0
*227. Tuff, analcimic, gray; undulating contacts	.2
*226. Oil shale, light-brown; contorted zone; some pods of tuffaceous material. Sample is tuff	2.0
225. Oil shale, medium-brown; weathers to thin plates	2.6
224. Tuff, undulating contacts; pods as much as 6 in. thick	.2
223. Oil shale, light- to medium-brown; weathers to thin plates	6.0
222. Marlstone, thick-bedded, and some light-brown oil shale near top. (Yellow X painted on rocks near base of exposure.)	6.0
Section offset into next gully to north. Units 222–233 measured in second most southerly gully which has exposures of uppermost white-weathering zone.	
221. Marlstone, light-brown; exposures poor	10.0
*220. Oil shale, medium- to dark-brown. Samples are dark-brown oil shale at base of unit and medium-brown oil shale 10 ft above base	11.0
*219. Marlstone, light-brown with thin protruding ledges of very fine grained tuffaceous sandstone. Poorly exposed. Sample is tuffaceous sandstone 15 ft above base	29.0
218. Sandstone, very fine grained; has organic debris and rusty pinhead spots	.3
217. Marlstone, brown; weathers platy; poorly exposed. Base of a distinctly brown weathering unit	12.0
Section offset to north.	
216. Marlstone; poorly exposed	13.0
215. Oil shale, light- to medium-brown, and white marlstone; unit poorly exposed	30.0
*214. Limestone, white, crystalline, dolomitic; many crystal cavities caused by removal of gypsum(?). About 160 ft below top of member and 240 ft above top of Mahogany ledge. Described by Donnell (1961, p. 857)	1.0
213. Marlstone, light-brown; weathers platy and slabby	15.0
212. Marlstone, light-brown; a massive bed	2.0
211. Marlstone; weathers to thin plates	5.0
210. Marlstone, light-brown; massive bed; weathers orange brown	2.4
209. Oil shale, medium- to dark-brown; weathers platy	2.4
208. Tuff zone. Five thin tuff beds alternating with light-brown oil shales. Poorly exposed. About 215 ft above top of Mahogany ledge. (Yellow T 5 painted on marlstone above unit.)	3.5
*207. Tuff, analcimic; weathers rusty brown; weathers to prominent reentrant on slopes	1.0

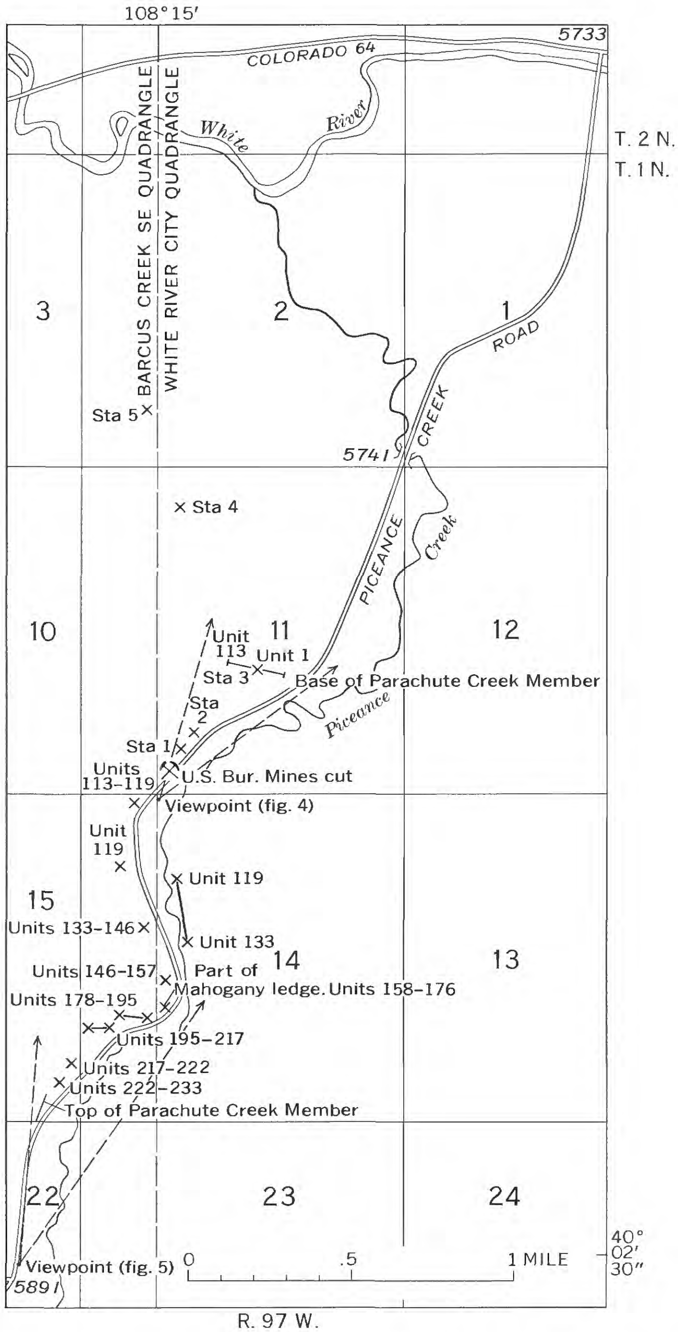


FIGURE 3.—Locations of the measured section of the Parachute Creek Member on lower Piceance Creek. Numbered units refer to units described in the measured section. Station numbers refer to sample localities of data shown in table 10.

Complete section of the Parachute Creek Member of the Green River Formation along lower Piceance Creek—Continued

Parachute Creek Member—Continued

	Thickness (feet)
206. Oil shale, light- to medium-brown; weathers to thick plates	4.6
205. Sandstone, light-brown, very fine grained	.8
204. Oil shale, light-brown; intercalated with beds of marlstone about ¼ in. thick	3.2

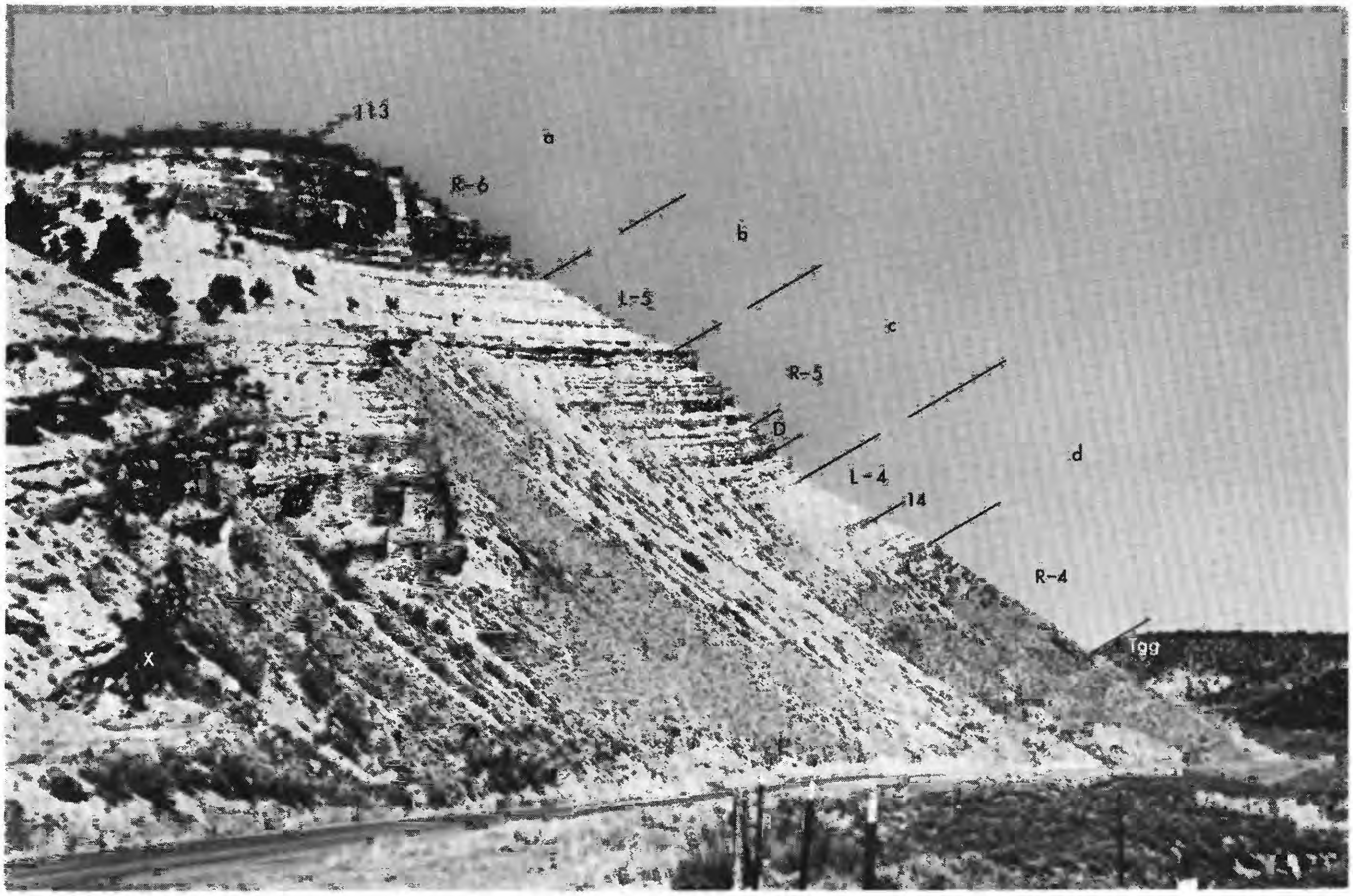


FIGURE 4.—Lower part of the Parachute Creek Member on lower Piceance Creek. Lowercase letters refer to units of Bradley (1931, pl. 4*A*). Numbers prefixed by R and L refer to zones rich or lean in oil shale. Numbers 14 and 113 refer to units described in the measured section in this report. D marks the dawsonitic zone. X indicates the U.S. Bureau of Mines cut in the zone of dawsonitic rocks. Tgg, Garden Gulch Member.

Complete section of the Parachute Creek Member of the Green River Formation along lower Piceance Creek—Continued

Parachute Creek Member—Continued

	Thickness (feet)
203. Oil shale; weathers platy	1.0
*202. Tuff, analcimic, white to light-green; weathers white with rusty spots	1.5
201. Oil shale, medium-brown	3.0
200. Tuff, analcimic, yellow-brown	.04
199. Oil shale, medium-brown; weathers to thin plates	2.8
*198. Tuff, analcimic, light-yellow-brown, persistent; weathers blocky	.1
197. Oil shale, light-brown	10.0
196. Marlstone, light-brown	23.0
*195. Oil shale, dark-brown; weathers platy, blue gray	1.0
Section offset to north along this bed. Units 195-178 measured in gully that has a large sandstone boulder at the mouth. Yellow circle and UP painted on boulder	
194. Marlstone; forms plate-covered slope	6.0
193. Marlstone, light-brown; forms prominent ledge. (Yellow 8A painted on ledge.)	3.0
192. Marlstone, light-brown; weathers white	2.7
*191. Oil shale, medium-brown	2.0
*190. Marlstone, light-brown, poorly exposed	11.0
*189. Marlstone, light-brown, and some tuffaceous sandstone and sandy marlstone; unit poorly exposed. Some medium-brown oil shale at base. Samples are oil shale at base of unit; tuffaceous sandstone 2.6, 3.6, and 5.6 ft above base; and tuffaceous marlstone 7.6 ft above base	165
*188. Marlstone; poorly exposed. Samples are tuffaceous marlstone 15 ft above base, light-yellow carbonaceous marlstone 21 ft above base, and light-brown silty marlstone 0.4 ft below top of unit	26.0
*187. Sandstone, red-brown, massive, tuffaceous, very fine to medium-grained. Conspicuous unit (fig. 5)	7.0
186. Marlstone, light-brown, and intercalated thin-bedded red-brown sandstone. (Base about 85 ft above Mahogany ledge, but greater true thickness of interval may be masked by slumping.)	5.0
*185. Marlstone, light-brown, and some intercalated light- to medium-brown oil shale. 15 ft below top is tuffaceous carbonaceous siltstone and very fine grained sandstone	35.0

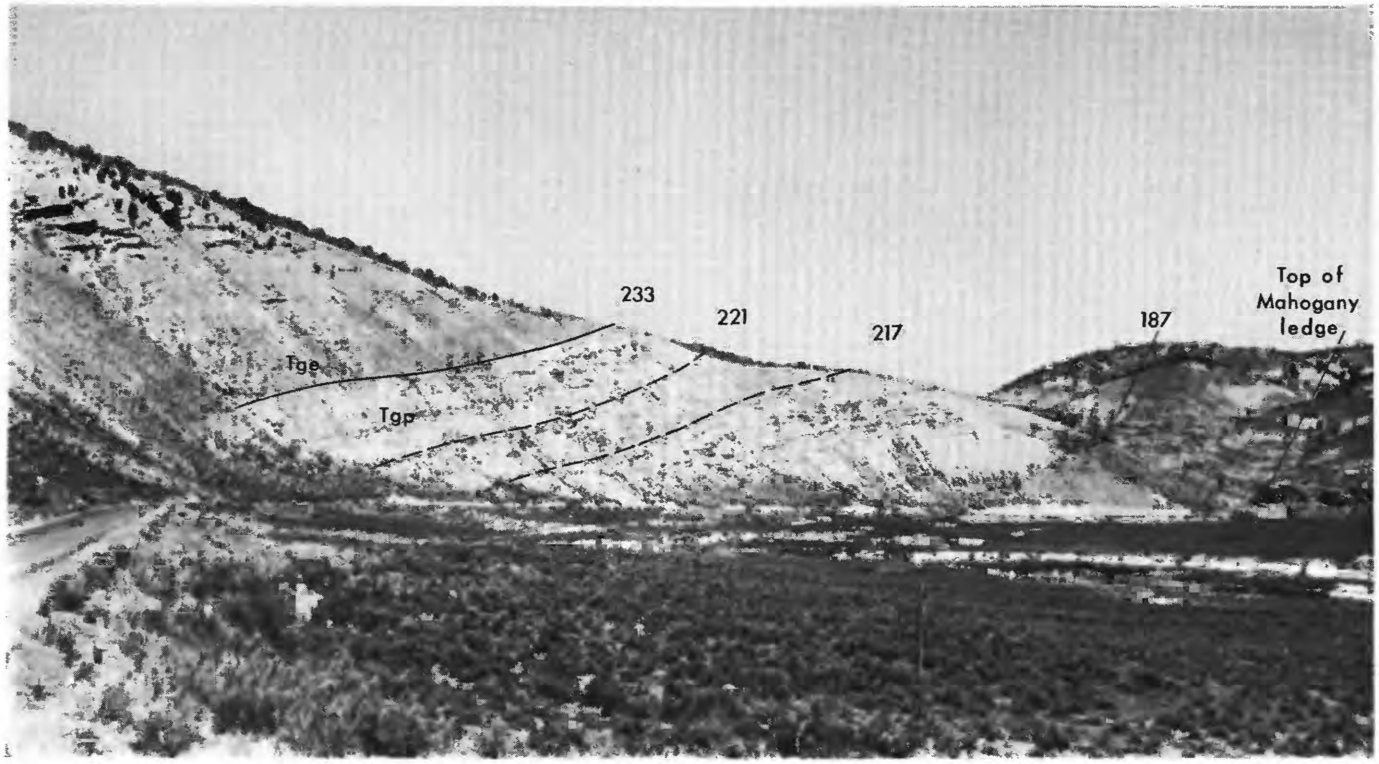


FIGURE 5.—Upper part of the Parachute Creek Member on lower Piceance Creek. Numbers refer to units described in the measured section. Unit 187 is a distinctive sandstone. Interval between units 217 and 221 is a sequence of rock that weathers distinctively brown. Tge, Evacuation Creek Member; Tgp, Parachute Creek Member.

Complete section of the Parachute Creek Member of the Green River Formation along lower Piceance Creek—Continued

Parachute Creek Member—Continued

		Thickness (feet)
184.	Oil shale, medium-brown	2.3
183.	Oil shale, dark-brown; weathers blue gray. Overturned fold axis trends N.35°W., plunges 10° NW	.5
182.	Marlstone, light-brown, weathers to brittle plates	11.7
181.	Oil shale, medium-brown; weathers white	.4
180.	Marlstone, light-brown	16.1
179.	Marlstone; weathers to brittle plates; poorly exposed	5.5
178.	Marlstone, light-brown; upper 1 foot has light-brown oil shale	3.0
	Section offset to north to good exposures of Mahogany ledge.	
*177.	Marlstone, light-brown, and intercalated light-brown oil shale 5 ft above base. Probable position of the A-groove	10.0
176.	Oil shale, light- to dark-brown; lighter colors increase upward. Top of the Mahogany ledge (fig. 5)	5.0
*175.	Tuff, analcimic, orange-brown; smooth lower contact; undulating upper contact; persistent bed. Informally referred to as the false marker bed. Mapped by G. N. Pipiringos and W. J. Hail, Jr., as top of Mahogany ledge (oral commun., 1970)	.7
*174.	Oil shale, dark-brown. Sample is from 4.5 ft above base	7.9
*173.	Oil shale, platy, rust-brown; efflorescent salt coatings	1.0

Complete section of the Parachute Creek Member of the Green River Formation along lower Piceance Creek—Continued

Parachute Creek Member—Continued

		Thickness (feet)
*172.	Oil shale, dark-brown, laminated; weathers blocky and blue gray. (Black 40 painted on outcrop 0.7 ft above base.)	7.8
*171.	Tuff, analcimic; undulating upper and lower contacts; persistent bed	2
*170.	Oil shale, dark-brown, laminated; weathers gray	1.5
*169.	Tuff, analcimic, orange-brown; persistent bed. The Mahogany marker	.1
*168.	Oil shale, dark-brown to red-brown, laminated; weathers gray; smooth face on outcrop. Sample is from 1 ft above base	1.8
*167.	Oil shale, dark-red-brown, laminated; weathers blue gray with rusty stains on outcrop. Samples are from base and 1 ft above base. The Mahogany bed	3.3
*166.	Marlstone, pale-yellowish-brown; massive bed in which calcite predominates over dolomite; darker brown discontinuous stringers of analcime- and dolomite-rich rock. Some beds of clear analcime. Distinctive bed. Sample is channel sample of massive brown marlstone. Samples 1–13, from this entire 31.25-cm-thick sequence, were studied in detail (fig. 13)	1.0
*165.	Oil shale, dark-brown; weathers to smooth surface, blue gray. Samples are from 1, 3, and 4 ft above base	5.0
*164.	Tuff, analcimic; pods 0.3 ft thick. Undulating contacts	.3

Complete section of the Parachute Creek Member of the Green River Formation along lower Piceance Creek—Continued

Parachute Creek Member—Continued

		Thickness (feet)
163.	Oil shale	0.3
*162.	Tuff, analcimic, orange-brown; smooth contacts	.08
*161.	Oil shale, dark-red-brown. Sample is from 2.5 ft above base. Samples 200–218, from a 20.6-cm-thick sequence beginning at base of unit, were studied in detail (figs. 11, 12)	6.1
*160.	Tuff, analcimic; weathers light brown; smooth contacts	.1
159.	Oil shale, dark-red-brown, laminated; weathers to smooth gray face	2.5
158.	Oil shale, dark-brown, laminated; weathers to alternating layers of light to dark blue gray. Thin discontinuous dolomite laminae weather to light orange brown. (Yellow 7P painted at base of fresh exposures in cut at curve in the road.)	1.0
157.	Tuff; undulating contacts	.15
156.	Oil shale, dark-brown; weathers blocky to slabby	5.2
155.	Oil shale, dark-brown; weathers papery	1.1
154.	Tuff, Undulating contacts, persistent bed. Makes groove in weathered outcrop. (Yellow 70 painted on outcrop.)	.25
153.	Oil shale; weathers slabby to blocky	3.4
152.	Oil shale, laminated; weathers to smooth face	.6
151.	Oil shale, medium-brown; weathers blocky to slabby	2.5
150.	Oil shale, dark-brown, laminated; weathers papery	1.1
149.	Tuff zone. Four tuffs, ½–1 in. thick, weather orange brown and are separated by dark-brown oil shale. Zone forms reentrant in exposure	.5
148.	Oil shale, dark-brown, laminated; weathers slabby	5.0
147.	Oil shale, dark-brown, laminated; low specific gravity; weathers to white flat face on outcrop	1.3
*146.	Oil shale, dark-brown; weathers blue gray, with large solution cavities 1.5 ft in diameter; makes projecting square-faced ledge; has a wavy thin bed of tuff at top. Samples are residue and leached rosette material collected from cavity near yellow X. (Yellow X painted on cliffs that are just north of curve in road.)	6.0
	Section offset 1,000 ft to north on west side of road to same unit exposed on the north side of a tributary of Piceance Creek in the S½NW¼ sec. 14, Barcus Creek SE (7½-min) quadrangle.	
145.	Oil shale; weathers blocky; conspicuous leached cavities	15.5
144.	Oil shale, medium- to dark-brown. Tuff 0.1 ft thick 1.5 ft above base. Vuggy zone above the tuff	3.25
143.	Oil shale. Top and bottom light brown and fissile; middle part light brown and blocky. Reentrant 3 ft below top has irregular pinching and swelling pods of analcimic tuff 0.02–0.5 ft thick	4.5
142.	Oil shale. Blue-gray-weathering ledge in upper 2.4 ft with 2 tuffs 0.5 ft and 1.3 ft below top; lower 3 ft medium brown and blocky	5.4
141.	Oil shale, dark-brown; weathers to thin plates in rounded slope in upper part; forms blue-gray-weathering ledge in lower part	2.2
140.	Oil shale, medium-brown, papery; has small rusty concretions of dolomite(?) in top 0.4 ft.	2.0
139.	Oil shale, light-brown; conspicuous recess at top possibly caused by weathering of a tuff	3.0
138.	Oil shale, light- to medium-brown; weathers blocky; has cavities 0.2–1 ft in diameter. Thin tuff at base	2.25
137.	Oil shale, dark-brown; forms ledge	1.2
136.	Tuff, weathered; undulating contacts	.5
135.	Oil shale, dark-brown; dolomite pebbles; forms ledge	1.0
134.	Tuff pods, 0.4–1.2 ft thick	1.0
*133.	Oil shale, dark-brown; weathers blue gray and blocky. Has flat brown dolomite pods. Papery where most intensely weathered. Good marker bed. Marked 7 M in yellow paint	3.0
	Section offset to same bed on east side of Piceance Creek valley from a point on a nose 30 ft above Piceance Creek road.	
132.	Tuff, regular contacts; persistent bed. Base of the Mahogany ledge	.2
*131.	Oil shale; mostly medium brown; weathers slabby to blocky. 1 ft above base a cavity zone from leached saline material is overlain by a 1-in. light bed of dolomite. Samples are weathered material from near cavity: dark-brown oil shale from cavity zone, and the light dolomite bed	3.9
*130.	Marlstone, light-yellow-brown to brown; poorly exposed; forms slope covered with brittle chips. Samples are marlstone and pod material from upper 1 ft of unit. Probable position of the B-groove	33.5
129.	Oil shale, poorly exposed; weathers more papery toward top. Top of R-6 zone	6.0
128.	Oil shale, medium- to dark-brown; darkest beds form blue-gray ledges ¼–2 in. thick	5.5
127.	Oil shale, leached; marks saline zone	.5
*126.	Oil shale, dark-brown; weathers blue gray; efflorescent salts abundant; thin beds give outcrop fluted appearance. Middle of unit is cavity zone. Sample is weathered oil shale at base of unit	6.1
125.	Marlstone, light-brown; weathers platy and blocky	6.0
124.	Oil shale, light-brown; weathers papery	1.0
123	Oil shale, light-brown; efflorescent salts; at top is dark-blue-weathering bed with flat pods of dolomite	3.8
122.	Oil shale, dark-brown; weathers blue gray	2.6
121.	Tuff; undulating lower contact, even upper contact; continuous bed. (Section offset to north from base of outcrop at spur of hill along irrigation ditch, where tuff is exposed and marlstone of unit 119 is just underground.)	.2

Complete section of the Parachute Creek Member of the Green River Formation along lower Piceance Creek—Continued

Parachute Creek Member—Continued

	Thickness (feet)
*120. Oil shale, medium- to dark-brown; some efflorescent salt. Samples are dark-brown oil shale. (Exposed on east side of the creek valley over the jointed marlstone described below.)	0.5
*119. Marlstone, light-brown. The jointed bed conspicuously jointed 1-2 in. apart; joints strike N. 48° W., dip 85° NE., and give blocky appearance. 1.9 ft above base is thin zone of oval cavities ½-¾ in. thick and 2 in. long filled with mixture of quartz, calcite, dolomite, feldspar, and some analcime and dawsonite. Base about 75 ft below base of Mahogany ledge. Samples are cavity filling containing some dawsonite, brittle marlstone 0.8 ft below cavity zone. A good marker bed; marked by yellow 7F at cliffs on east side of irrigation ditch on east side of Piceance Creek valley	5.7
Section offset to same bed on west side of road west of Piceance Creek. Painted yellow 7F on outcrops at sample locality of unit 119.	
*118. Oil shale, dark-brown; weathers papery; forms ledge	4.0
*117. Oil shales, medium-brown. Some weather to blue-gray ledges; others weather to paper ledges. A rubbly ledge-ribbed slope. Sample is from a blue-gray ledge	15.0
116. Oil shales, light- to medium-brown; weather to gray, shaly, partly covered slope	20.0
115. Oil shale, dark-brown; weathers blue gray; has brown flat dolomite pods; forms ledge	6.0
*114. Oil shale, light- to medium-brown; weathers papery to slabby; forms poorly developed ledges. A ½-in.-thick light dolomite at 21.7 ft. above base. Sample is light-brown oil shale 6 ft above base. Lower 3 ft is covered. A tuff 0.2-0.4 ft thick is 9 ft above base of this unit in draw to north	25.0
*113. Oil shale, dark-brown; weathers blue gray; has flat rusty brown dolomite pods. Sample contains some dawsonite. (Yellow 6A painted on this bed at base of outcrops west of and about 50 ft above road, nearly on the boundary of secs. 11 and 14, T. 1 N., R. 97 W., near the east edge of the Barcus Creek SE quadrangle	3.5
Section offset to north, where a similar 3.5-ft-thick bed is exposed above units 1-112 measured near center of sec. 11, T. 1 N., R. 97 W., White River City quadrangle. Sample from unit 113 is from outcrop in White River City quadrangle (fig. 4).	
112. Tuff	.04
111. Oil shale	3.8
110. Tuff	.02
109. Oil shale	.15
*108. Tuff, analcimic, light-gray	.02
107. Oil shale	2.1
106. Tuff	.02
105. Oil shale	.1
104. Tuff, yellow-orange	.01
103. Oil shale	6.5

Complete section of the Parachute Creek Member of the Green River Formation along lower Piceance Creek—Continued

Parachute Creek Member—Continued

	Thickness (feet)
102. Tuff	0.01
101. Oil shale	.25
100. Tuff, mottled	.02
*99. Oil shale; weathers gray blue. Sample contains some dawsonite	1.6
98. Tuff	.02
97. Oil shale; mostly light to medium brown, with some dark-brown beds	17.2
*96. Tuff, yellow-brown; dark petroliferous stain; very fine grained. (Yellow T 27 painted on outcrop.)	.06
95. Oil shale	.5
*94. Tuff, yellow-brown; contains albite and dawsonite; undulating contacts; persistent bed	.02
*93. Oil shale, medium- to dark-brown; some beds weather blue gray; some beds form ledges. Samples are dark-brown blue-weathering oil shales 3 and 6 ft above base that contain some dawsonite	33.2
92. Marlstone, light-yellow-brown, sugary-grained	.2
*91. Oil shale, medium- to dark-brown; some weathers blue gray. Sample is dark-brown oil shale from middle of unit	3.7
90. Tuff; weathers yellow orange; smooth contacts	.02
*89. Oil shale, light- to medium-brown; forms alternating slopes and ledges. Samples are light-brown oil shales 0.2, 4, and 9 ft above base. Some dawsonite	10.5
*88. Conglomerate; contains dolomite pebbles. (Yellow streak and 6A painted on outcrop.)	.5
87. Oil shale, light-brown, and fissile to platy and locally papery marlstone; forms thin ledges. Approximate base of upper oil shale group (Bradley, 1931, pl. 4*A*, letter a). Base of R-6 zone (fig. 4, this report)	3.3
86. Oil shale, light-brown; weathers gray, fissile. Approximate top of transitional beds (Bradley, 1931, pl. 4*A*, letter b). Top of L-5 zone (fig. 4)	6.7
85. Tuff; weathers yellow brown; laterally persistent	.1
84. Oil shale, light-yellow-brown; forms thin ledges and covered slopes; weathers fissile to platy	7.7
*83. Oil shale; weathers papery, blue gray	.5
*82 Conglomerate. Angular pebbles of dolomite in a coarse sand matrix	.17
*81. Oil shale, light-brown. Sample is from 2 ft above base	4.7
80. Tuff; weathers orange; smooth contacts	.04
*79. Oil shale, light- to medium-brown; weathers fissile to papery, blue gray. Some thin orange-weathering marlstone beds. Much covered slope. Sample is from marlstone bed	35.2
78. Oil shale, light-brown; weathers fissile. Base of L-5 zone	14.8
*77. Oil shale, dark-brown; weathers blue gray. Sample is from top of unit. Approximate top of lower oil shale group (Bradley, 1931, pl. 4*A*, letter c). Top of R-5 zone (fig. 4)	1.7
76. Tuff; persistent bed; smooth contacts	.02
75. Oil shale, dark-brown	.3
74. Tuff; undulating contacts	.1

Complete section of the Parachute Creek Member of the Green River Formation along lower Piceance Creek—Continued

Parachute Creek Member—Continued

Unit	Description	*Thickness (feet)*
73.	Oil shale, dark-brown; weathers papery, blue gray	0.9
72.	Tuff, yellow-orange; smooth contacts	.08
71.	Oil shale, brown; forms slope	5.0
*70.	Oil shale, dark-brown; weathers blue gray; forms ledge. Sample contains dawsonite. Base about 53 ft above tuff of unit 49	3.5
69.	Oil shale, light-brown, and light-brown marlstone; weathers fissile to platy and forms alternating ledges and slopes every 0.2–0.3 ft	4.2
68.	Tuff; sugary texture	.04
67.	Oil shale, light-brown; weathers platy	3.8
66.	Oil shale, dark-brown; weathers blue gray; contains dolomite nodules; upper 4 ft is ledge	6.2
65.	Marlstone, light-yellow-brown	.2
*64.	Oil shale, dark-brown; weathers blue gray. Sample is from 1.5 ft above base and contains dawsonite	3.6
63.	Tuff, oil-stained, dolomitic. (Yellow T 18 painted on a slab placed below the bed.)	.1
62.	Oil shale; weathers blue gray, papery. Unit is base of ledge	3.5
61.	Oil shale, yellow-brown to dark-brown; incompletely exposed	5.4
*60.	Marlstone, tuffaceous; weathers yellow orange. A tough rock	1.3
*59.	Tuff, analcimic, yellow-orange; sandy texture	.3
*58.	Oil shale, medium-brown; weathers papery. Sample is from 1 ft above base	4.4
*57.	Tuff, analcimic; undulating upper and lower contacts	.2
56.	Oil shale. Mostly covered slope	3.1
*55.	Oil shale, medium-brown; weathers blue gray, papery. Sample is from 1 ft above base	4.2
*54.	Tuff, analcimic, orange-brown; has thin dolomite bed near top	.3
53.	Oil shale	.9
*52.	Tuff, analcimic; undulating contacts; discontinuous bed. Sample contains dawsonite	.2
*51.	Oil shale, light-brown; weathers fissile to papery; some blue gray. Sample is from 5 ft above base	6.3
*50.	Oil shale, dark-brown; weathers blue gray; a few very thin tuffaceous beds. Sample is from 4 ft above base and contains dawsonite	4.7
*49.	Tuff, yellow-brown, analcimic, coarsely crystalline; undulating contacts. (Yellow paint on enclosing beds parallel to tuff.) Correlated with tuff 13 of table 10	.3
*48.	Oil shale, light- to dark-brown; weathers platy; contains gar-pike scales. Samples are from 2, 4.8, 5.8, 8.4, and 8.5 ft below tuff of unit 49, and all contain dawsonite. (Yellow 4 E1 painted at base of unit.)	8.5
47.	Marlstone. Tuffaceous even bed, smooth contacts	.1
*46.	Oil shale, medium-brown, and light-brown marlstone. Sample is medium-brown oil shale	4.4
45.	Oil shale, medium-brown, poorly exposed	3.5
*44.	Tuff, analcimic, red; weathers white; undulating contacts	.15
43.	Oil shale, dark-brown; weathers fissile	3.5
*42.	Oil shale, dark-red-brown; weathers to prominent smooth-faced blue-gray ledge. Samples are from top of unit (contains dawsonite); 0.5 and 1 ft below top; 2.5 ft below top (contains dawsonite); and base of unit. (Yellow circle painted on face of outcrop.)	3.3
41.	Oil shale, light-brown, poorly exposed	8.0
*40.	Oil shale, medium-brown; weathers blue gray; forms thin ledge; contains dawsonite. Samples are from 1.7 ft above base and near base	2.7
*39.	Oil shale; weathers papery; distorted beds; probably marks a saline zone. Sample is from 2 ft above base	5.6
*38.	Oil shale, poorly exposed. Sample is from 2.3 ft above base	4.7
*37.	Tuff, analcimic	.04
36.	Oil shale; contains intraformational conglomerate in lower 2 ft	6.1
*35.	Oil shale, dark-brown; weathers papery; distorted lower 0.5 ft. Samples are distorted oil shale and dark-brown oil shale 0.9 ft above base	2.8
*34.	Tuff, orange; contains dawsonite	.7
*33.	Oil shale, dark-brown; weathers papery. Top 1.2 ft of unit has efflorescent salts and may mark a saline zone. Two samples from the lowest 2.8 ft above base	6.2
*32.	Oil shale, medium-brown. Sample is from 1.8 ft above base and contains dawsonite	4.0
*31.	Marlstone, gray-green	.08
*30.	Oil shale, light- to medium-brown, with 0.08 ft olive-drab dolomite bed at base. Sample is from dolomite bed	1.0
*29.	Oil shale, dark-brown; weathers blue gray. Conglomeratic with yellow-brown dolomite blebs 3 in. in diameter and $^{1}/_{16}$ in. thick. Sample is from 3.9 ft above base	7.0
*28.	Tuff; weathers yellow. (Yellow T 8 and streak parallel to bed painted on rock.)	.1
*27.	Oil shale, dark-brown; weathers papery. Sample is from 1 ft above base and contains dawsonite	2.0
*26.	Oil shale, gray-brown, hackly; forms a slope. Near top is a tuff zone consisting of thin tuff and tuffaceous marlstone. Sample is marlstone and contains dawsonite	3.6
25.	Oil shale; has orange-weathering dolomite concretions in upper 1 ft	2.0
24.	Tuffs. Two thin beds separated by oil shale	.1
23.	Oil shale	.55
*22.	Tuff; weathers yellow; forms reentrant in outcrop	.2
21.	Oil shale; weathers blue gray, papery. Base of cliff-forming oil shales (fig. 4). Approximate base of Parachute Creek Member (Bradley, 1931, pl. 4*A*). Base of R–5 zone	1.0
*20.	Oil shale and marlstone, light-brown. Sample is marlstone 1.7 ft below top. Top of L–4 zone	2.5
*19.	Tuff, analcimic	.02
18.	Oil shale, light-brown; weathers fissile	1.3
*17.	Tuff, analcimic	.04

Complete section of the Parachute Creek Member of the Green River Formation along lower Piceance Creek—Continued

Parachute Creek Member—Continued	*Thickness (feet)*
*16. Oil shale, light- to dark-brown; weathers fissile; forms slope littered with small shale plates. Samples are dark-brown oil shale 2.7 ft below top and light-brown oil shale near base of unit	27.9
*15. Oil shale; mostly covered slope. Sample is medium-brown oil shale	6.0
14. Oil shale; forms ledge	7.0
*13. Oil shale and marlstone; forms mostly covered slope littered with small brown chips of brown oil shale and plates of light-brown to orange marlstone. Sample is light-brown oil shale 2 ft above base. Base of L-4 zone	30.0
12. Oil shale, medium- to dark-brown. Top of series of ledge-forming shales. Top of R-4 zone. (Yellow 3 painted at top of ledge.) Base of unit mapped by G. N. Pipiringos and W. J. Hail, Jr., as contact between Parachute Creek Member and Garden Gulch Member	15.0
11. Marlstone, light-yellow, silty, ostracodal	3.5
*10. Oil shale, dark-brown. Sample is from about 7 ft above base	22.0
9. Marlstone, light-yellow-brown, silty	.3
*8. Oil shale, medium- to dark-brown; some weathers blue gray. Forms alternating slopes and ledges in 5-ft intervals. Sample is dark-brown oil shale	19.5
7. Oil shale; weathers fissile; partly covered slopes	4.0
6. Oil shale, dark-brown; weathers blue gray; forms ledge	3.0
5. Oil shale, medium- to dark-brown. 1 ft of dark-brown oil shale at base	4.5
4. Marlstone; weathers to slope littered with light-yellow-brown chips; poorly exposed	31.5
3. Marlstone and oil shale, light-brown; oil shale increases toward top; forms a ledge	9.0
2. Marlstone and oil shale, light-brown; forms covered slope	12.2
*1. Oil shale, light- to dark-brown; darkest beds weather blue gray; forms a ledge. Sample is dark-brown oil shale	10.1
Thickness of Parachute Creek Member (rounded)	1,185.0
Garden Gulch Member (part):	
Shale, olive-gray, clayey but slightly dolomitic; forms partly covered slope	6.2
Oil shale, light-brown; weathers papery. (Yellow 1 painted on small outcrop.)	3.0
Shale, olive-gray, clayey; subfissile to hackly fracture	25.0
Incomplete thickness of Garden Gulch Member (rounded)	34.0

Other workers have chosen contacts of the Parachute Creek Member on lower Piceance Creek differently. Correlations of the data in this report with those of earlier workers are shown in figures 4 and 6. Bradley (1931, pl. 4*A*) placed the basal contact of the Parachute Creek about 210 feet higher stratigraphically than we do. Donnell (1961, pl. 51) chose the contact at the base of the lowest oil-shale-rich zone, which coincides closely with our contact. G. N. Pipiringos and W. J. Hail, Jr. (oral commun., 1970), in geologic mapping of the White River City and Barcus Creek SE quadrangles, respectively, have chosen the bottom of a generally well exposed and easily mappable bench of dark-brown oil shale at the top of smooth and rubble-strewn slopes as the base of the Parachute Creek Member. This persistent bench is about 120 feet above the contact we have chosen with the aid of laboratory study.

The position generally mapped as the base of the Parachute Creek Member seems to lie above the position chosen in drill cores or from detailed laboratory study of rocks from measured sections. This difference in selection of the contact may account for what has been interpreted in some areas to be extreme basinward thickening of the Parachute Creek Member within short distances.

The R and L designations shown in figure 6 were used by Donnell and Blair (1970, p. 76) to describe units of rich and lean oil shale, respectively. These designations were easily applied to the section on lower Piceance Creek and also correlate easily with rock units described by Bradley (1931, pl. 4*A*). (See figs. 4 and 6.)

From the data in the diagrammatic section on plate 3 and in photograph *A* on plate 4 of Bradley (1931), a thin Parachute Creek Member was designated that included only the most organic rich parts of the sequence of carbonate-rich rocks. He apparently used the top of the oil-rich zone now called the Mahogany ledge as the top of the Parachute Creek Member. This, of course, automatically made the Evacuation Creek of Bradley thicker than the Evacuation Creek of later workers.

RIO BLANCO SECTION

A well-exposed complete section of the Parachute Creek Member (764 ft) was measured in the cliffs along the north side of Piceance Creek beginning at the base of the member at the west end of the gravel pit (NW¼SW¼ sec. 5, T. 4 S., R. 94 W.) and continuing westward to the draw intersected by the west boundary of sec. 6, T. 4 S., R. 94 W., Rio Blanco County, Colo. (fig. 7). The gravel pit is 1.8 miles west of the junction of the Piceance Creek road and Colorado Highway 13 at Rio Blanco, Colo. The area is shown on the Rio Blanco 7½-minute quadrangle.

The contact between the Parachute Creek Member and the underlying Anvil Points Member is gradational. Eastward from the gravel pit, and down section, the rocks become more silty and sandy and contain less carbonate. The top of the Parachute Creek Member is only moderately well exposed, but the contact with the sandstones of the overlying Evacuation Creek Member generally can be found to within a few feet.

The lithic details of the section follow, and the mineral composition of 98 samples is shown in table 6.

Complete section of the Parachute Creek Member of the Green River Formation near Rio Blanco, in secs. 5 and 6, T. 4 S., R. 94 W., Rio Blanco County, Colo.

[Section measured by D. A. Brobst and J. D. Tucker. * indicates sample data in table 6]

	Thickness (feet)
Evacuation Creek Member (part):	
Sandstone, tuffaceous, light-brown; consists chiefly of albite, quartz, analcime, and dolomitic cement. Partly covered slope	50+
Incomplete thickness of Evacuation Creek Member	50+
Parachute Creek Member:	
162. Marlstone, light-brown	7.5
*161. Oil shale, dark-red-brown, pyritic, laminated; weathers blue gray; forms ledge	2.3
160. Oil shale; mostly light brown, with some dark-brown beds a few inches thick; weathers platy	6.8
159. Tuff, analcimic	.02
158. Marlstone, light-brown, sandy, well-exposed	14.5
*157. Oil shale, dark-brown, pyritic; forms ledge. (Yellow line painted on bed.)	.7
Section offset to same bed in next gully to east, where yellow line and triangle are painted on bed.	
156. Oil shale, light- to dark-brown, laminated; interlayered with light-brown marlstone. (This unit better exposed on south side of road and creek.)	20.0
*155. Oil shale, dark-grayish-black, pyritic, laminated; weathers blue gray and platy; forms ledge. Samples 1–37, collected at 100-ft lateral intervals, were studied in detail (figs. 7, 17)	.3
Section offset to top of westernmost large roadcut on north side of road. (See fig. 7.)	
154. Oil shale, medium- to dark-brown, laminated, poorly exposed	22.3
153. Oil shale, medium- to dark-brown. (Well exposed in road cut.)	10
*152. Oil shale, medium- to dark-brown; forms tuff zone with nine analcimic tuffs ¼ to ½ in. thick. Sample is tuff from lowest and thickest of nine beds	6.0
*151. Oil shale, medium- to dark-red-brown, pyritic; laminated, but massive bedded on these fresh exposures. Sample is dark-red-brown oil shale from base of unit	7.2
*150. Sandstone dike, tuffaceous, light-brown to gray; 1 ft thick; strikes N. 75° E.; dips vertically	0
*149. Oil shale, medium- to dark-red-brown, laminated. Massive beds. Deep blue gray weathered bed near base of outcrop is base of unit. Sample is dark-red-brown oil shale 5 ft above base of unit	13.5
Section offset to next roadcut to east. (See fig. 7.)	
*148. Oil shale, very weathered. Sample is light-brown oil shale	10.0
147. Oil shale, medium-brown; weathers chippy	2.9

Complete section of the Parachute Creek Member of the Green River Formation near Rio Blanco—Continued

Parachute Creek Member—Continued

	Thickness (feet)
145. Oil shale, light- to medium-brown; weathers chippy	2.0
144. Tuff, analcimic, light-rust-brown	.02
143. Oil shale, medium-brown; weathers chippy	7
*142. Tuff, analcimic, light-rust-brown	.02
*141. Oil shale, medium-brown, laminated	.4
140. Tuff, analcimic, evenly bedded	.04
139. Oil shale, medium- to light-brown, and 5 analcimic tuffs ⅛–½ in. thick. (Yellow triangle painted on rock.)	4.9
138. Marlstone, light-brown, resistant; hard layer, weathers to orange-brown sandy surface	.5
Section offset to exposure on west wall of an adit to the east.	
137. Oil shale and marlstone, light- to dark-brown, intercalated	1.3
*136. Tuff, dark-brown, biotitic; has some organic debris; weathers out in blocky fragments; contacts undulate; maximum thickness 6 in	.3
135. Oil shale, medium-to dark-brown, massively bedded, includes a light-brown marlstone. (Yellow M above a horizontal yellow stripe is painted on marlstone.)	9.2
134. Marlstone, light-gray; beds 2 in. thick with some intercalated light-brown laminated oil shale	1.5
*133. Oil shale, dark-brown, laminated. Sample from top of unit. Zone of 3 thin tuffs in lower part	2.3
132. Marlstone, light-brown. (Yellow circle 4 in. in diameter painted on bed.)	2.0
*131. Oil shale; mostly medium brown. Sample of medium-brown oil shale 3.1 ft above base. Other samples are dark- and medium-brown oil shale	7.4
130. Marlstone, light-brown; weathers orange brown	.04
129. Oil shale, medium- to dark-brown	3.0
*128. Marlstone, light-brown; weathers to sandy surface. Sample is whitish orange marlstone at base	2.0
127. Sandstone dike, tuffaceous; about 4 in. thick; strikes N. 20°W.; dips 65° NE. About 10 ft above the road, dike is offset to right and extends to top of outcrop. (Large yellow D painted on outcrop at road level just west of dike.)	0
*126. Oil shale, dark-brown; thin pods and intercalations of marlstone. Sample is dark-brown oil shale 2 ft below top	8.0
Section offset to gully to east.	
*125 Marlstone, light-gray, tuffaceous	.08
124. Oil shale, medium-brown; weathered plates form partly covered slope	11.1
123. Marlstone, light-brown	2.0
122. Oil shale, dark-red-brown; weathers blue gray; forms ledges a few inches thick	4.1
121. Marlstone, light-brown, and medium-brown oil shale	5.5
*120. Oil shale, dark-brown, well laminated; weathers blue gray. Sample is from dark-brown ledge-forming bed 6 in. thick	2.3
119. Oil shale, medium-brown, poorly exposed	6.9
118. Oil shale, dark-red-brown to medium-brown;	

Complete section of the Parachute Creek Member of the Green River Formation near Rio Blanco—Continued

Parachute Creek Member—Continued

		Thickness (feet)
*117.	Marlstone, tuffaceous	.6
116.	Oil shale, dark-red-brown; weathers blue and slabby; has some interbedded light-brown marlstone	6.0
115.	Oil shale, light- to medium-brown; contains some dark-brown beds	4.8
*114.	Tuff, light-brown, dolomitic	.2
113.	Oil shale, red-brown, poorly exposed	3.0
*112.	Tuff	.2
111.	Oil shale, medium- to dark-brown	1.1
*110.	Oil shale, dark-brown, pyritic; weathers blue; forms ledge. (Yellow streak painted on rock.)	6.3
*109.	Oil shale, dark-red-brown, pyritic; forms ledge	.3
*108.	Oil shale, medium- to dark-red-brown. Sample is medium-brown oil shale	4.4
107.	Oil shale, dark-red-brown, pyritic; 1-ft-thick ledge at top of unit	6.5
106.	Covered unit	5.5
*105.	Oil shale, dark-brown	10.0
104.	Marlstone, gray, silty	.1
103.	Oil shale, medium- to dark-brown; weathers platy	7.7
*102.	Tuff; consists of analcime in a deep-blue matrix	.17
101.	Oil shale, dark-red-brown	.4
*100.	Marlstone, tuffaceous, brown; resistant dense bed	.1
99.	Oil shale, medium- to dark-brown	1.8
98.	Marlstone, brown; resistant bed	.1
97.	Oil shale, dark-brown	2.1
96.	Marlstone, gray; resistant bed	.2
	Section offset to lowermost outcrop in gully to east.	
*95.	Oil shale, dark-red-brown, laminated; weathers blue gray	3.3
94.	Marlstone, dark-brown, sandy, resistant; forms ledges between layers of light-brown oil shale. (Yellow streak on bed below at west end of outcrop.)	9.6
*93.	Tuff, dark-brown, analcimic; even contacts; saturated with petroliferous material	.1
92.	Marlstone, light-brown	.8
*91.	Marlstone, tuffaceous, sandy, gray; weathers light orange brown	.3
*90.	Oil shale, dark-brown. Sample is from 2.2 ft above base	4.3
89.	Tuff, analcimic; undulating contacts	.05
88.	Oil shale, medium-brown	1.2
*87.	Tuff, analcimic, rust-brown, continuous; undulating contacts	.08
86.	Marlstone, light-brown, thin-bedded; contains chert pods 1-2 in. thick and as much as 6 in. long. (Yellow P painted on outcrop.)	3.6
*85.	Marlstone, light-gray, dolomitic; massive bed	.4
84.	Oil shale, medium- to light-brown	3.4
83.	Tuff, analcimic, light-brown	.02
82.	Oil shale, light-brown	.7
81.	Tuff, analcimic, light-brown	.02
80.	Oil shale, light- to medium-brown	3.2
79.	Tuff, analcimic, light-brown	.02
78.	Oil shale, light- to medium-brown	2.2
77.	Tuff	.1
76.	Marlstone, light-brown	1.0
75.	Oil shale, dark-red-brown; weathers blue gray	2.3

Complete section of the Parachute Creek Member of the Green River Formation near Rio Blanco—Continued

Parachute Creek Member—Continued

		Thickness (feet)
*74.	Tuff, analcimic; weathers brown; has inclusions of oil shale and marl; undulating contacts; 84 ft above Mahogany ledge. Well exposed along road (fig. 7). Possibly correlates with unit 163 in the pipeline section	5.2
*73.	Oil shale, medium- to dark-brown. Sample is from top of unit	7.7
72.	Oil shale, interbedded medium- to dark-brown, weathers platy. (Yellow circle painted on outcrop at top of unit.)	12.4
*71.	Oil shale, medium- to dark-brown. Sample is dark-brown oil shale 2 ft below top of unit. Top of unit contains discontinuous pods of analcimic tuff as much as ½ in. thick. Tuff and enclosing oil shale also sampled. (Yellow triangle painted on outcrop about 15 ft above road.)	3.4
*70.	Marlstone, light-brown	4.1
*69.	Oil shale, dark-red-brown, laminated; contains some tuff pods. Sample is dark-red-brown oil shale. (Yellow dot on outcrop just below sampled area.)	4.3
*68.	Sandstone, tuffaceous, light- to dark-brown	.6
67.	Oil shale, dark-red-brown, laminated	3.0
66.	Sandstone, tuffaceous, dolomitic, laminated	.2
65.	Oil shale, dark-brown, laminated	.9
*64.	Sandstone, calcareous	.6
*63.	Oil shale, light- to medium-brown. Sample is light-brown oil shale	1.2
62.	Tuff, analcimic, rust-brown. (Painted yellow T 19 just above bed.)	.01
61.	Marlstone, light-brown; poorly exposed in middle. (Forms base of outcrop that lies about half way between 2 curves in road.)	6.9
60.	Covered slope	26.4
*59.	Marlstone, light-brown, and a few dark-brown beds of oil shale a few inches thick; includes 4 layers of discontinuous pods of rust-brown tuff about ½ in. thick at 6.3, 9.2, 9.5, and 11.5 ft above base. Top of unit is analcimic rust-brown tuff about ½ in. thick. Sample is uppermost tuff. Probable position of the A-groove	12.3
*58.	Oil shale; mostly light brown with some thin beds of dark-red-brown. Sample is light-brown oil shale 4 in. below top. Small fold; axis trends N 10° W. Top of the Mahogany ledge. (Yellow 5 painted on outcrop.)	5.4
*57.	Clay, white, chloritic and dolomitic.	.1
56.	Marlstone, gray- to blue-weathering	3.1
*55.	Marlstone, and 2 thin tuffs. Sample is marlstone	.6
54.	Marlstone, gray	.1
*53.	Tuff, analcomic; weathers rust brown	.1
*52.	Marlstone, light-gray	.5
*51.	Tuff, analcimic, medium-brown; some biotite	.1
50.	Marlstone; laminated with tuff	.4
*49.	Tuff, analcimic; weathers light brown. (Yellow T9 painted under tuff in bend of road.) "The false marker"	.7
48.	Oil shale, medium- to dark-red-brown	16.3
*47.	Sandstone dike, tuffaceous, light-brown, fine-grained, poorly sorted; 1 ft thick; strikes N. 70° E.; dips vertically; some organic debris	0

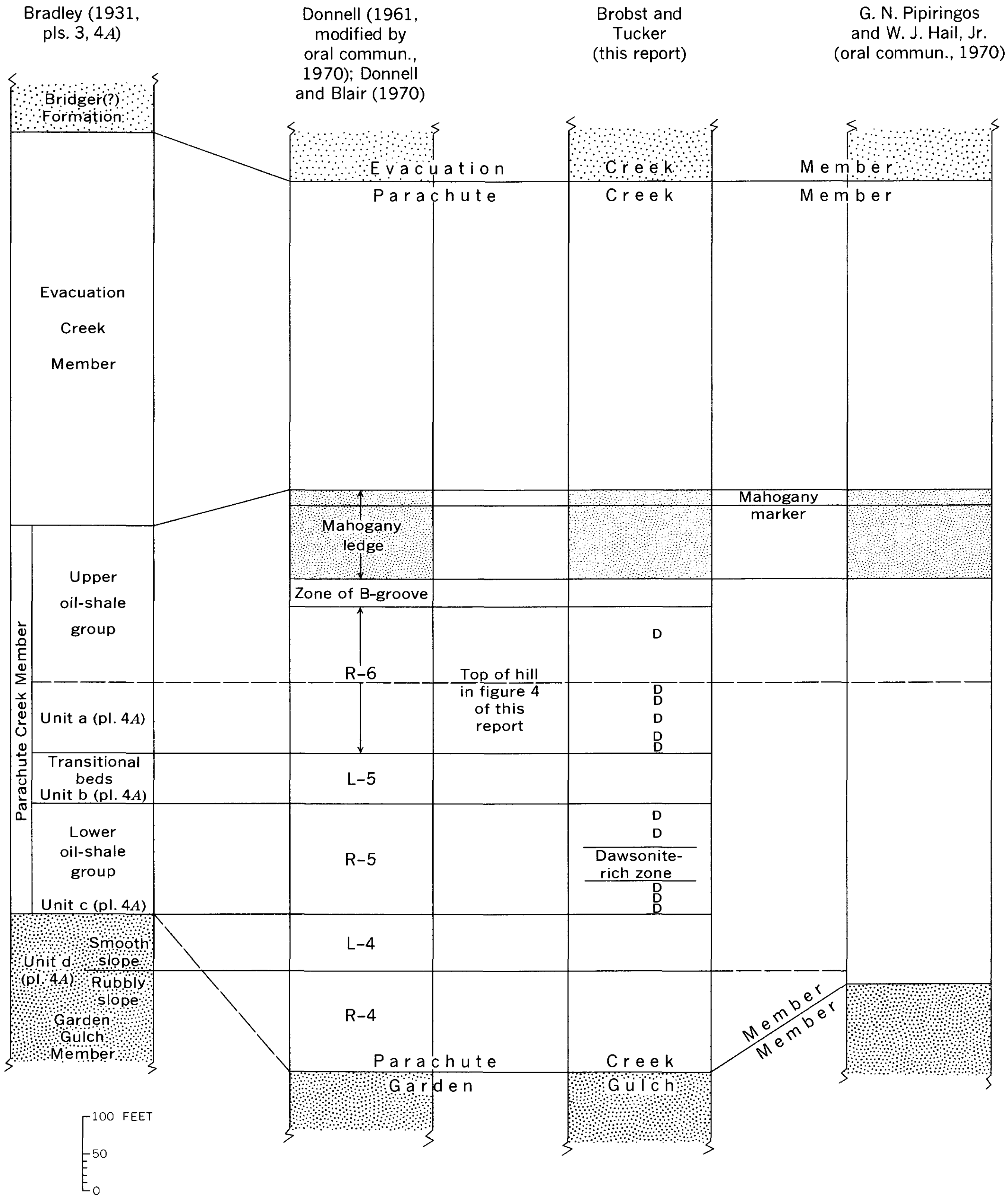


FIGURE 6.—Nomenclature used for the Parachute Creek Member on lower Piceance Creek. D, occurrence of dawsonite. Numbers prefixed by R and L refer to zones rich or lean in oil shale.

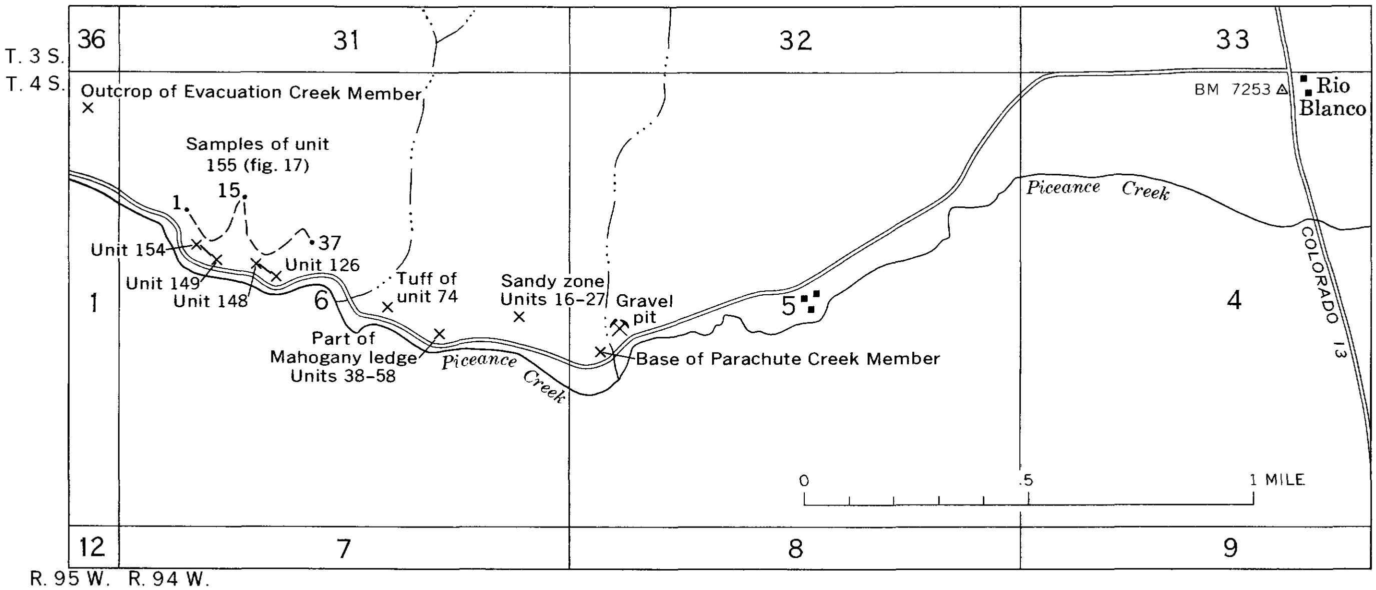


FIGURE 7.—Location of the measured section of the Parachute Creek Member near Rio Blanco. Numbers refer to units described in the measured section.

Complete section of the Parachute Creek Member of the Green River Formation near Rio Blanco—Continued

Parachute Creek Member—Continued

	Thickness (feet)
*46. Tuff, analcimic; lesser amounts of quartz and alkali feldspar; minor amounts of illite in weathered samples only. Samples of fresh and weathered rock. The Mahogany marker. (Yellow + painted on tuff.)	0.7
45. Oil shale, medium-brown	2.8
*44. Marlstone, light-brown, dolomitic; massive beds to 4 in. thick. Samples from a 9.5-cm-thick sequence were studied in detail (figs. 14, 15)	1
*43. Oil shale, dark-red-brown; weathers blue gray. The Mahogany bed	1.5
*42. Dolomite; thin bedded in beds ¼–½ in. thick	1.0
*41. Oil shale, dark-brown	3.0
*40. Dolomite, brown	0.7
39. Oil shale, dark-brown; contains some marlstone beds to 1 in. thick	2.3
38. Oil shale, medium-brown; contains some light-brown marlstone. (Yellow ML painted on outcrop near road level.)	4.5
Section offset to 2 blue-gray beds exposed beneath talus in gully to east.	
*37. Oil shale, medium- to dark-red-brown; laminated beds 1–2 in. thick; weathers blue gray and platy. Samples are dark-brown oil shale 10.6 and 15.9 ft above base. (Ledge painted yellow.)	21.5
*36. Oil shale, dark-red-brown; weathers blue gray	.2
35. Oil shale, medium-brown to red-brown; weathers blue gray; strikes N. 90° W.; dips 10° SW	5.9
*34. Oil shale; mostly light to medium brown. Samples are dark-brown oil shale in uppermost bed (0.1 ft thick) and lowermost bed (0.2 ft thick). Lowermost good unit of oil shales	5.5
*33. Tuff, analcimic, biotitic. Base of the Mahogany ledge	.1
32. Marlstone, gray to brown. Probable position of B-groove	7.4
*31. Tuff, analcimic, persistent bed; weathers dark brown	.1
30. Marlstone, thinly laminated	.3
*29. Dolomite, sandy; weathers powdery	.1
28. Marlstone	1.3
*27. Sandstone, analcimic, very fine grained; weathers rust brown. Sandstones in this part of section chosen by Duncan and Belser (1950) as uppermost beds of their lower sandy member. This is 267 ft above the base of Parachute Creek Member as defined by our measurement	.7
26. Marlstone	1.2
*25. Sandstone, dolomitic, light-brown, fine-grained, thinly bedded	.5
24. Marlstone, gray and brown, laminated; weathers platy	6.9
*23. Tuff, orange-brown. (Painted yellow T 4.)	.1
*22. Marlstone, tuffaceous, thin-bedded, laminated	2.1
*21. Marlstone, dark-brown	.5
*20. Tuff; contains analcime, quartz, and alkali feldspar; weathers blocky. (Bed painted yellow.)	.7
19. Marlstone, weathered, well-exposed	9.0
18. Marlstone, partly exposed	16.5
Section offset to next gully east.	
*17. Marlstone, gray to light-brown; weathers brown; strikes N. 15° W.; dips 10° SW	16.5
*16. Sandstone, calcareous, gray, fine to very fine grained, crossbedded	3.9
*15. Marlstone, light-chocolate-brown to gray, brittle; weathers to rust-brown plates and slabs; some tuffaceous material. Samples are tuffaceous marlstone at base of unit, brown marlstone 5.5 ft above base, and tuffaceous marlstone 25 ft above base	32.5

Complete section of the Parachute Creek Member of the Green River Formation near Rio Blanco—Continued

Parachute Creek Member—Continued

	Thickness (feet)
*14. Marlstone; various shades of brown. Unit contains pyrite nodules, efflorescent salts, and cavities (formerly occupied by saline minerals?). Common organic debris and fossils of leaves, twigs, and insects. Eight samples. (Yellow 3C at base of outcrop.)	10.0
13. Marlstone, platy weathering, poorly exposed	11.0
*12. Marlstone, gray to brown; somewhat siliceous—dense, tough, and brittle. Samples are gray-brown marlstone from basal beds and dark-brown marlstone with insect impressions. (Yellow 3A painted 3 ft above base.)	23.8
11. Poorly exposed sequence	81.0
*10. Marlstone, gray, well-laminated. Sample is dense marlstone near top of unit. Also sampled was 0.5-ft-thick tuff 2.1 ft above base. (Yellow paint on sampled bed of marlstone.)	16.8
*9. Marlstone, gray, and some silty beds; contains tuffaceous pods ⅛ in. thick, especially in upper 8 ft. Samples are gray marlstone and tuffaceous siltstone	15.2
*8. Tuff, analcimic and dolomitic	.1
7. Marlstone, gray	.3
6. Siltstone and very fine grained sandstone; contains some asphaltite	.2
5. Marlstone, gray	2.4
4. Sandstone, fine-grained, poorly sorted, evenly bedded; contains ostracodes and clay galls. (Marked RB-1A in yellow.)	.5
3. Marlstone, gray, poorly exposed	9.5
2. Sandstone, gray-brown, fine-grained, poorly sorted	.7
*1. Marlstone, gray, laminated; weathers platy	5.0
Section ends at base of exposures in ditch along north side of Piceance Creek road at west end of gravel pit. (See fig. 7.) Considered to be the base of the Parachute Creek Member. Eastward, the rocks are less well exposed, but sandstone and siltstone, characteristic of the Anvil Points Member, increase in abundance.	
Thickness of Parachute Creek Member (rounded)	764.0

Suggested correlations of our section with those of earlier workers are shown in figure 8. Donnell (1961, pl. 53) chose the lower contact of the Parachute Creek Member at about the same stratigraphic position as we did. Duncan and Belser (1950) placed the contact at the top of sandstone beds (our units 25 and 27 in the Rio Blanco section) about 270 feet above the base we chose for the Parachute Creek (D. C. Duncan, oral commun., 1970). Thus, they seemed to have a thinner Parachute Creek Member—only 445 feet thick as compared with 735 feet measured by Donnell (1961, pl. 53) and 764 feet measured by us.

MINERAL COMPOSITION

The mineral fraction of most rocks examined in this study of the Parachute Creek Member consists of mixtures of dolomite, calcite, quartz, potassium feldspar, albite, analcime, illite, and pyrite. Dawsonite was detected only in oil shale on lower Piceance Creek. Small amounts of chlorite occur in some of the rocks, and biotite and (or) muscovite occur(s) in some of the beds of tuff. Thin coatings of gypsum line some fractures.

Nearly all these rocks are extremely fine grained and contain some tightly bound organic materials that impregnate the rock, coating and masking the mineral grains and making the physical separation of the minerals from each other and from the organic matter very difficult. Tisot and Murphy (1960) found that oil shale from the Mahogany ledge near Rifle, Colo., is composed of particles that are 90 percent silt and clay size. They also reported that the mineral fraction is 83.8 and 55.4 percent (by weight) in oil shales which, respectively, assay 28.6 and 75 gallons of shale oil per ton of rock. These features of the rock make the study of the mineral composition by standard microscopic techniques unsatisfactory. X-ray diffraction methods, although having certain limitations, do provide a rapid means of acquiring mineralogic data.

LABORATORY WORK

PROCEDURES

Samples weighing about 4 ounces (100 g) and taken from about 1 inch (2–3 cm) of stratigraphic thickness of the freshest both common and unusual rocks were collected for X-ray study from the measured sections. Samples of the tuffs generally represent the thinnest stratigraphic intervals; many of these beds are less than 1 inch thick. After initial sampling was completed in the three measured sections and the X-ray results were examined, further sampling was done at selected localities to provide material for study of the details of vertical and lateral variation in the composition of selected units of rock, including the dawsonite zone on lower Piceance Creek.

Samples from the three measured sections were routinely prepared for X-ray study by being ground in a hammer mill. The resulting powder was pelletized at 22,000 pounds per square inch in a hydraulic press. X-ray diffraction patterns of the pellets were made with Norelco equipment (operated at 40 kv; 20 ma; scale factor, 8; multiplier, 1; time constant, 4). Diffraction data from CuKα_1 radiation were recorded from scans of the sample through an arc of 60° 2θ on 100-unit chart paper at the rate of 2° 2θ per minute. Values for peak intensity, expressed as height of the peak in chart units above base line, produced by the Norelco equipment are summarized or shown in tables 4–7 and 11 and in figure 21.

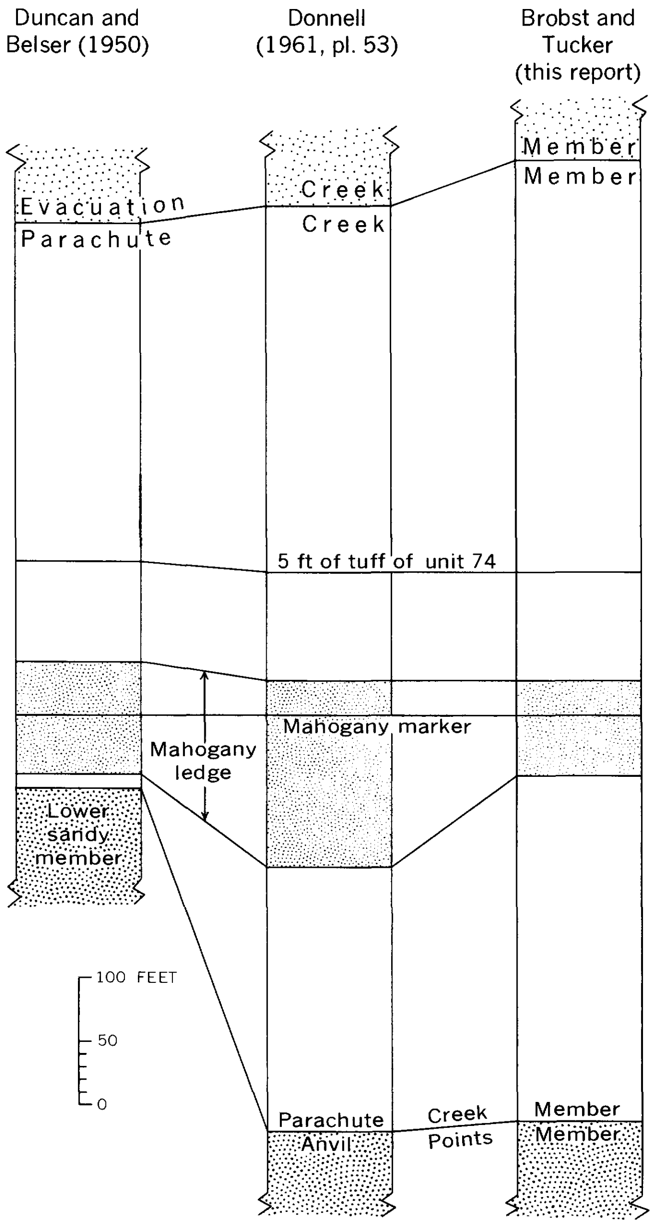


FIGURE 8.—Nomenclature used for the Parachute Creek Member in the Rio Blanco section.

Samples of dawsonitic and other rocks described in tables 2 and 8–10 and in figures 16–19 were prepared as described above, but diffraction patterns were obtained by use of Picker-Nuclear equipment (operated at 35 kv; 20 ma; scale factor, 3K; time constant, 1). The diffraction patterns, also from CuKα_1 radiation, were recorded as described above.

Data compiled in figures 10, 12, 13, 15, 20, and 22 pertain to samples obtained by use of a dental drill from sawed slabs of rock. The powder thus obtained also was made into pellets as described above, but because of the small amounts of material available, the pellets consisted of a thin coating of powder on cellulose backs. Diffraction patterns were made with Picker-Nuclear equipment operated at the settings described above.

Diffraction patterns of all the rocks were examined uniformly by measuring the height of the apex of the peak above base line on chart paper divided into 100 units. One peak was measured for each mineral detected; these selected peaks are shown in table 1. The values thus obtained were compiled or summarized in the tables and figures in this report.

DISCUSSION

Diagnostic peaks to be read for the minerals in a given suite must be chosen to avoid use of 2θ positions where the cumulative effect of the presence of more than one mineral leads to ambiguity as to how much of the peak height is attributable to any one mineral. When possible, the most intense peaks for each mineral are used, but this is not always possible or practical. In this study, the 20.9° 2θ peak for quartz was used rather than the more intense 26.6° 2θ peak because illite enhances the latter peak. The second highest peak for analcime occurs at 15.8° 2θ, which is close to the 15.6° 2θ major peak of dawsonite, but our equipment was able to differentiate the two peaks well enough for our purposes in this study.

Detection of dawsonite in the samples was considered of enough importance to conduct some grinding experiments to determine the optimum method of sample preparation for assuring the appearance of the maximum peak height in the diffraction pattern. Two samples of dawsonitic oil shale from the section on lower Piceance Creek were crushed and then ground and homogenized in a mixer mill. At various timed intervals of 5–50 minutes, part of the sample was removed and X-rayed. Results are shown in table 2. The data show that prolonged grinding reduces the height of the dawsonite peak to a much greater degree than the peaks of the other minerals. In the entire length of the grinding time, the peak height of carbonate minerals and illite was more affected than was that of quartz and feldspar. Short grinding time, to insure the recording of the maximum peak height of the dawsonite, seemed desirable.

Another sample that contained both dawsonite and analcime from outcrops on lower Piceance Creek was crushed and passed through the hammer mill. The sample was then split: half was sieved, and the different fractions were X-rayed; the other half was ground further in a mixer mill for 5 minutes and was sieved, and the different fractions were X-rayed. The results of these experiments are shown in table 2*B*. The X-ray data from the sample that was ground only in the hammer mill show considerable uniformity;

TABLE 1.—*Two-theta position of X-ray peaks measured for use in tables of mineral composition of rocks in the Green River Formation*

Mineral	Peak position (degrees 2θ)
Chlorite	6.3
Illite[1]	8.8
Gypsum	11.7
Dawsonite	15.6
Quartz	20.9
Analcime	26.0
Potassium feldspar	27.6
Albite	28.0
Calcite	29.5
Dolomite	31.0
Pyrite	33.1

[1]Mica (biotite or muscovite) was distinguished from illite in tuffs by visual examination of hand specimens.

slight variation is present, however, and the greatest peak height for dawsonite was found in the finest size fraction. The X-ray data from the sample processed in both the hammer mill and the mixer mill show no greater variation, but the peaks for dawsonite were smaller in this half of the sample than in the other. Thus, routine processing of the samples would seem to only require crushing and grinding in the hammer mill to provide a material in which dawsonite can be detected with almost maximum sensitivity by X-ray diffraction without sacrifice of sensitivity in detection of the associated minerals.

Peak heights obtained for the finest fractions of the samples shown in table 2*B* suggest that the values measured for the samples obtained with the dental drill should be similar. The data in table 2*B* also indicate that the chances of detecting dawsonite are enhanced in the finest fractions of the sample without appreciable change in the peak of the other minerals.

It would be ideal to demonstrate that the threshold of detection is the same for all minerals and that equal peak heights of various minerals indicate equal amounts of those minerals. Such is not the case because of many factors affecting the response of minerals to X-rays. Some of these factors are the time of grinding and the particle size of the sample, the presence of coatings of other substances on the surfaces of the grains, the crystallinity of the mineral and any variation in the composition, and the tendency for minerals to lie in preferred orientation in the sample. A detailed discussion of the factors is beyond the scope of this paper; the complexities of the subject have been discussed by Jackson (1964) and Schultz (1964).

Much effort in this study to translate X-ray diffraction peak height directly to percentage of the mineral, by the use of standards prepared from minerals and matrices obtained from rocks of the Parachute Creek Member, produced no satisfactory scheme for achieving the highly desirable combination of simple procedures and a short time for routine application to a large number of samples.

Experiments with standards for quartz in a dolomite matrix from the Parachute Creek Member indicated that the value of the height of the 20.9° 2θ quartz peak is about 80 percent of the value of the amount of quartz in the standards, but these results are semiquantitative at best. Jackson (1964, p. 256) found that generally more than 10 percent quartz must be present in a sample before the 20.9° 2θ peak is legible.

Fine-grained disseminated dawsonite could not be separated from the other components of the rocks, so satisfactory standards for quantitative evaluation of X-ray peak heights could not be established. Smith and Milton (1966, p. 1034) estimated, however, that as little as 3 percent dawsonite can be detected by X-ray diffraction. Comparison of X-ray data with chemical determinations of acid-soluble aluminum has not yielded satisfactory correlation. More involved and time consuming procedures for the quantitative determination of dawsonite, however, have been described by Smith and Young (1969).

Analcime seems to be highly sensitive to detection by X-ray diffraction. Tuffs that contain about 50 percent analcime yielded a major peak whose apex was not recorded at the standard settings of the X-ray equipment. Preparation of standards was hindered because the analcime in these rocks contains myriads of small inclusions of other minerals.

Potassium feldspar and albite standards made from materials in these rocks were not obtainable. There is no reason to suspect, however, that the two groups of feldspars have any significant differences in sensitivity to X-rays. Equal peak heights of the two feldspars in these samples probably do indicate nearly equal amounts of the feldspars.

Dolomite and calcite seem to be similarly sensitive to detection by X-rays. X-ray diffraction provides a satisfactory and rapid method for distinguishing between the two minerals and for estimating their relative abundance in the sample.

Pyrite seems to be less easily detected in the X-ray diffraction patterns than should be expected from its high degree of crystal symmetry. Thin-section study suggests that accessory amounts of pyrite are commonly disseminated in the rocks of the Parachute Creek Member, but most legible peaks for pyrite are restricted to those patterns from samples in which pyrite is abundant and coarsely crystalline enough to be seen easily by the unaided eye.

TABLE 2.—*X-ray data, expressed by X-ray peak height in chart units, from grinding experiments on dawsonitic rocks from the lower Piceance Creek section*

A. PEAK HEIGHT VARIATION WITH GRINDING TIME

	Dark oil shale, unit 32						Dark oil shale, unit 50					
Grinding time (min)	5	10	20	30	40	50	5	10	20	30	40	50
Dawsonite	29	17	10	9	7	7	84	48	32	23	13	10
Quartz	31	27	27	26	28	27	38	32	37	37	29	29
Potassium feldspar	16	14	14	14	14	14	17	13	14	14	11	10
Albite	8	5	5	5	5	6	6	6	5	5	4	5
Dolomite	22	19	16	15	14	14	17	15	19	12	9	9
Calcite	9	7	7	7	6	7	0	0	0	0	0	0
Illite	14	9	8	6	6	6	11	7	5	5	3	3

B. PEAK HEIGHT VARIATION WITH SIZE FRACTION AND GRINDING TIME

Method of sample preparation	Mesh	Dawsonite	Analcime	Quartz	Potassium feldspar	Albite	Dolomite	Illite	Weight percent
Hammer mill only	-28	71	14	31	9	10	34	7	100
Hammer mill and sieve	+100	71	14	32	9	11	35	7	44
	-100 +200	64	14	30	10	11	34	7	18
	-200 +300	71	13	31	9	11	37	8	7
	-300	77	13	33	11	11	34	7	29
Hammer mill and 5-min mixer mill; no sieve		50	12	32	9	10	34	6	100
Hammer mill, 5-min mixer mill, and sieve	+100	44	18	32	9	9	31	6	20
	-100 +200	47	13	32	9	10	30	6	22
	-200 +300	45	14	30	9	8	31	6	13
	-300	51	12	31	11	10	33	5	44

Most of the clay minerals in these rocks are illite type. They tend to lie in a preferred orientation and to yield the highest peak at 8.8° 2θ. Muscovite and biotite have their major peaks at the same position, and examinations of hand specimens and thin sections were used to draw the distinctions noted in the various tables.

Reproducibility of the X-ray data, a measure of the precision of the method, is affected by some of the factors already discussed. Some test pellets of selected samples were prepared and scanned four times —twice on each side—the second scan on each side at 90° to the first scan. The ranges of the peak height of the four scans of the test pellets are shown in table 3. The ranges are small, although the range of 2–4 chart units in the larger peaks is a smaller variation than the spread of 3 chart units on smaller peaks. The differences in the ranges cannot be evaluated fully, but they are greatly dependent on the homogeneity of the sample, physical and chemical characteristics of the minerals—including any preferred orientation—and variation in the performance of the X-ray generator, goniometer, and recording systems. Test patterns were run frequently during the periods of X-ray work to monitor variation in the operation of the X-ray and recording equipment. We consider the ranges of peak height to be sufficiently small that they probably do not interfere with the use of the data in the manner reported here.

The settings on the X-ray equipment previously stated produced legible results on the chart from one scan of the sample for most of the minerals detected. Those peaks whose tops were not recorded on the chart at the standard setting were reported in the tables as values with a plus sign. The plus signs were most frequently needed with values for analcime in tuff beds and for dolomite in oil shale and marlstone, but only about 7 percent of all values compiled in tables 4, 5, and 6 had to be reported with plus signs.

We concluded from this study that peak heights obtained by X-ray diffraction from these samples,which were uniformly prepared and exposed to X-rays at similar settings of the equipment, do offer a good means of not only determining the minerals present but also comparing the relative abundance of given minerals in different samples. More complex methods requiring preparation of mineral standards of questionable quality supplemented by chemical analyses of the samples were rejected because of the required time and because the final values expressed as weight percent of the mineral are based on mathematical manipulation that easily may make them appear more precise and accurate than they are.

A few further words of explanation and caution about reading and interpreting the X-ray data in the tables and figures of this report may be helpful. The amount of a mineral in a sample is expressed by the X-ray peak height in chart units in parts of 100. The greater the value of the peak height, the greater the abundance of the mineral. The peak height of a mineral must not be read as percentage of that

TABLE 3.—*Range of X-ray peak height in chart units from four replicate scans of test samples*

Stratigraphic position and sample description	Dawsonite	Analcime	Quartz	Potassium feldspar	Albite	Dolomite	Calcite
Norelco equipment							
U.S. Bur. Mines cut:							
Dark-brown oil shale 4.8 ft below tuff 13 (table 10)	33-36	41-44	30-34	17-20	21-25	43-46	—
Dark-brown oil shale 6.8 ft below tuff 13	79-84	—	33-37	22-25	10-12	14-18	15-18
Lower Piceance Creek section:							
Dark-brown oil shale 3 ft above base unit 93	12-14	9-10	16-19	15-17	7-10	62-66	45-47
Dark-brown oil shale, unit 50	61-66	—	35-41	21-22	9-11	20-21	27-29
Picker-Nuclear equipment							
U.S. Bur. Mines cut:							
Dark-brown oil shale 4.8 ft below tuff 13	28-35	37-42	26-28	11-13	14-16	31-35	—
Dark-brown oil shale 6.8 ft below tuff 13	89+	—	34-36	19-21	8-9	15-16	13-14
Lower Piceance Creek section:							
Dark-brown oil shale 3 ft above base unit 93	14-15	7-8	16-18	12-13	6-9	62-64	44-47
Dark-brown oil shale, unit 50	79-81	—	39-43	16-19	6-8	17-18	26-28
Rio Blanco section:							
Dark-brown oil shale, unit 16	—	35-37	20-24	9-11	5-7	53-59	41-50

mineral in the sample. The values for the peak heights, however, are a measure of the relative abundance of different minerals in the same sample and indicate variations in the mineral composition between samples. The tables and figures of X-ray data are, therefore, informative when read either vertically or horizontally.

OIL SHALE AND MARLSTONE

The mineral fraction of the oil shale and marlstone in the three measured sections is composed chiefly of various mixtures of dolomite, calcite, quartz, potassium feldspar, albite, analcime, illite, and pyrite. Dawsonitic oil shale and marlstone, found only along lower Piceance Creek, will be discussed separately because of their potential economic value. Relative abundance of the minerals in the oil shale and marlstone determined from X-ray diffraction patterns is shown in tables 4, 5, and 6. A summary of the data from 196 samples of oil shale and marlstone is shown in table 7. The values of peak height were combined into groups, each consisting of a range of 10 chart units of peak height. From these groups, the modal class (the group with the largest number of values) and the median class (the group which includes the value of the middle sample of the entire suite of samples) were determined for each mineral in each rock type. The imbalance in the number of samples for each rock type merely reflects the distribution of the samples collected.

Dolomite has long been recognized as the predominant carbonate mineral of the marlstone and oil shale (Bradley, 1931, p. 20). Dolomite was detected in all the samples, except one of oil shale on lower Piceance Creek. According to the wide range of peak heights recorded, the abundance of dolomite varies greatly. Table 7 suggests a general decrease in abundance of dolomite from the marlstones, which contain lesser amounts of organic matter, to the dark oil shales, which contain greater amounts of organic matter.

Calcite is much more restricted in its occurrence than dolomite. Nearly half of the 196 samples summarized in table 7 do not contain detectable calcite, and where present, calcite generally is less abundant than dolomite. However, calcite was detected in more samples and in greater abundance relative to dolomite in samples above the Mahogany ledge than below it in each of the three measured sections (tables 4, 5, and 6). In 69 samples taken above the Mahogany ledge, calcite was detected in 59 samples and was relatively more abundant than dolomite in 14 samples. In 127 samples taken below the Mahogany ledge, calcite was detected in only 42 samples and was more abundant than dolomite in only one.

Analcime is a common mineral in these rocks and was detected in 85 percent of the 196 samples that are compared in table 7. Dark oil shale contains more analcime than lighter oil shale and marlstone. About half the 196 samples of the four types of rock yielded X-ray peak heights for quartz within the range of 11-20 chart units, suggesting no great variation in the relative abundance of quartz in many of these rocks.

Some potassium feldspar was detected in about 95 percent of the 196 samples of oil shale and marlstone. In the three types of oil shale, nearly half the samples are in the modal class, which coincides with the median class of the medium and dark oil shales. The potassium feldspar is mostly sanidine, but some samples contain microcline and orthoclase, according to X-ray examination by the technique of Wright (1968, fig. 3). Potassium feldspar was detected in more samples than was albite and occurs perhaps in slightly greater relative abundance than albite.

TABLE 1.—*Mineral composition, expressed by X-ray peak height in chart units, of rocks in stratigraphic succession from the pipeline section*

[D, dark brown; M, medium brown; L, light brown; Cl, chlorite; Py, pyrite; Gp, gypsum. Leaders (--), not detected]

Unit sampled	Analcime	Quartz	Potassium feldspar	Albite	Dolomite	Calcite	Illite	Remarks
				PARACHUTE CREEK MEMBER				
				Rocks above Mahogany ledge				
230	64	25	43	56	--	--	4	Tuff, micaceous (Cl, 5).
228	86+	16	7	60	51	44	5	Tuff, micaceous.
226	23	25	18	10	52	--	5	Oil shale, pyritic (D) (Py, 5).
224	25	17	14	12	65	29	5	Oil shale (D).
218	29	14	9	11	70	51	3	Oil shale (M).
211	20	15	11	10	53	34	4	Oil shale, pyritic (D) (Py, 2).
198	48	19	17	--	65	7	4	Oil shale, pyritic (D) (Py, 5).
195	45	15	14	13	81	13	7	Oil shale (L).
187	85+	44	4	3	--	--	--	Tuff.
186	28	18	9	11	80	19	--	Oil shale (D).
163	59	37	29	--	--	12	--	Tuff (Cl, 9).
162	27	19	16	15	75	20	--	Oil shale (D).
150	84+	41	14	6	24	18	8	Tuff, micaceous (Cl, 5).
147	26	13	9	12	63	44	5	Oil shale (D).
146	88+	51	11	14	--	8	8	Tuff, micaceous (Cl, 8).
142	11	17	12	8	82	48	4	Oil Shale (M).
140	12	16	12	9	74	58	3	Do.
137	17	17	11	12	88+	29	--	Marlstone.
137	22	90	--	--	21	6	--	Pod in marlstone.
				Mahogany ledge				
136	28	15	12	14	85+	--	--	Oil shale (D).
130	75+	24	12	9	18	8	--	Tuff. Mahogany marker.
124	21	18	13	42	85+	--	9	Oil shale (D). Mahogany bed.
117	22	12	10	20	85+	12	4	Oil shale (M).
111	17	15	14	25	72	38	7	Oil shale (D).
110	86+	56	24	24	--	--	--	Tuff.
				Rocks below Mahogany ledge				
109	11	12	32	46	56	8	--	Oil shale (M).
108	--	21	22	27	78+	--	9	Oil shale, burned(?).
96	63	18	33	27	38	14	--	Tuff.
93	--	13	18	--	86+	--	4	Oil shale (M).
92	68+	5	--	70	--	--	3	Tuff, muscovitic.
87	30	14	--	6	86+	--	5	Oil shale (M).
86	83+	32	15	30	--	--	--	Tuff.
84	14	12	19	14	80+	--	--	Oil shale (L).
77	15	37	41	24	75	--	6	Marlstone, tuffaceous.
76	9	26	24	5	94+	8	--	Marlstone, brecciated.
73	--	26	32	--	82+	--	3	Marlstone.
72	--	45	65	27	--	--	--	Tuff (Cl, 8).
63	--	12	6	5	87+	--	2	Cavity septum.
63	18	15	19	10	72	--	6	Oil shale (D) (Gp, 3).
61	--	43	57	55	--	--	5	Tuff.
57	38	15	18	12	51	--	5	Oil shale (L).
56	44	15	10	37	24	--	--	Tuff.
54	80+	45	10	--	6	--	--	Do.
48	80+	18	--	8	--	--	--	Do.
46	12	12	5	4	21	6	4	Oil shale (D).
44	50+	6	1	24	--	--	--	Tuff.
43	27	17	25	10	33	--	9	Oil shale (D).
42	78+	27	20	15	57	--	--	Tuff.
40	7	10	12	--	74+	--	1	Tuff, dolomitic.
39	11	8	4	4	35	--	4	Oil shale (M).
37	66	32	43	14	--	--	5	Tuff.
34	17	14	5	5	50	--	8	Oil shale (M).
33	66	43	44	16	--	--	7	Tuff.
31	70+	12	32	53	--	--	--	Tuff, micaceous (Cl, 8).
29	60+	11	9	10	--	--	--	Tuff (Cl, 7).
28	3	8	5	4	58	--	3	Oil shale (L).
27	8	14	8	7	88+	15	5	Pod, dolomitic.
25	19	16	10	8	57	--	9	Oil shale (M).
22	15	18	16	--	63	--	7	Marlstone (Py, 3).
20	4	9	7	15	85+	--	--	Marlstone, tuffaceous.
18	15	5	5	--	80+	--	--	Marlstone, tuffaceous (magnesite, 15).
14	3	3	4	4	85+	--	--	Marlstone; at top of unit.
14	4	27	7	--	75+	--	--	Marlstone; 0.6 ft above base.
13	60+	8	27	5	--	--	6	Tuff.
12	15	12	4	5	86+	--	6	Marlstone.

TABLE 4.—*Mineral composition, expressed by X-ray peak height in chart units, of rocks in stratigraphic succession from the pipeline section*—Continued

Unit sampled	Analcime	Quartz	Potassium feldspar	Albite	Dolomite	Calcite	Illite	Remarks
				PARACHUTE CREEK MEMBER—Continued **Rocks below Mahogany ledge—Continued**				
9	29	19	--	10	84+	--	6	Do.
6	32	20	12	12	21	--	16	Oil shale (M).
5	5	15	--	6	85+	--	8	Marlstone.
2	29	17	5	7	85	3	9	Do.
1	7	12	9	15	80+	--	5	Do.
				GARDEN GULCH MEMBER				
	--	35	14	17	14	13	21	Shale, silty.

TABLE 5.—*Mineral composition, expressed by X-ray peak height in chart units, of rocks in stratigraphic succession from the lower Piceance Creek section*

[D, dark brown; M, medium brown; L, light brown; Cl, chlorite; Py, pyrite; Gp, gypsum. Leaders (--), not detected]

Unit sampled	Dawsonite	Analcime	Quartz	Potassium feldspar	Albite	Dolomite	Calcite	Illite	Remarks
					EVACUATION CREEK MEMBER				
	--	55	36	22	31	19	20	3	Sandstone, tuffaceous (Cl, 13).
	--	32	20	23	60	--	85+	5	Sandstone, tuffaceous (Cl, 3).
					PARACHUTE CREEK MEMBER **Rocks above Mahogany ledge**				
232	--	30	21	13	9	22	30	7	Oil shale, pyritic (D) (Py, 5).
230	--	25	15	8	8	47	31	7	Oil shale, pyritic (D) (Cl, 3; Py, 2).
230	--	32	14	11	10	54	27	5	Oil shale, pyritic (D) (Py, 2).
228	--	90+	6	5	4	--	90+	4	Oil shale (L).
227	--	88+	32	28	18	--	43	22	Tuff.
226	--	85+	25	15	15	--	--	5	Do.
220	--	27	21	9	11	70	64	5	Oil shale (M); 10 ft above base.
220	--	17	13	12	10	64	76	4	Oil shale (D); at base.
219	--	60	23	38	46	67	3	4	Sandstone, tuffaceous.
214	--	3	15	16	9	63	80	5	Limestone.
207	--	68	39	26	28	43	3	--	Tuff.
202	--	73	73	14	10	--	--	--	Do.
200	--	85+	19	34	38	--	62	--	Do.
198	--	90+	4	6	14	--	73	--	Do.
195	--	36	10	75	65	71	57	3	Oil shale (D).
191	--	27	12	6	--	51	71	5	Oil shale (M).
190	--	18	7	5	5	51	90+	4	Marlstone.
189	--	8	24	33	43	22	64	4	Marlstone, tuffaceous; 7.6 ft above base.
189	--	--	35	48	50	32	--	7	Marlstone, tuffaceous; 5.6 ft above base.
189	--	17	31	41	78+	34	14	5	Marlstone, tuffaceous; 3.6 ft above base.
189	--	21	18	19	66	50	64	3	Marlstone, tuffaceous; 2.6 ft above base.
189	--	31	18	24	22	27	63	5	Marlstone, tuffaceous; at base.
188	--	9	26	30	36	44	58	3	Marlstone, silty; 0.4 ft below top.
188	--	16	16	5	9	62	78	6	Marlstone; 25 ft above base.
188	--	36	20	--	55	23	50	4	Marlstone; 21 ft above base.
188	--	37	26	28	50	25	15	5	Marlstone, tuffaceous; 15 ft above base.
187	--	22	22	--	77	67	11	4	Sandstone.
185	--	39	26	22	63	29	14	--	Do.
177	--	24	11	8	7	71	14	3	Oil shale (L).
					Mahogany ledge				
175	--	94+	54	4	5	--	--	--	Tuff. False marker.
174	--	22	11	9	5	63	25	3	Oil shale (D).
173	--	19	18	12	12	60	--	8	Oil shale (M) (Gp, 10).
172	--	29	14	8	7	54	17	5	Oil shale (D) (Gp, 5).
171	--	12	35	--	83+	--	--	--	Tuff.
170	--	29	31	10	10	81	--	8	Oil shale (D).
169	--	79	29	--	30	20	--	--	Tuff. Mahogany marker.
168	--	8	11	5	4	76	45	4	Oil shale (D).
167	--	24	17	7	9	40	4	7	Oil shale (D); 1 ft above base. Mahogany bed.
167	--	26	23	7	8	50	12	8	Oil shale (D) (Py, 6); at base. Mahogany bed.

TABLE 5.—*Mineral composition, expressed by X-ray peak height in chart units, of rocks in stratigraphic succession from the lower Piceance Creek section*—Continued

Unit sampled	Dawsonite	Analcime	Quartz	Potassium feldspar	Albite	Dolomite	Calcite	Illite	Remarks
				PARACHUTE CREEK MEMBER—Continued					
				Mahogany ledge—Continued					
166	--	2	9	6	6	43	87	3	Marlstone.
165	--	24	15	7	7	55	6	10	Oil shale (D); 4 ft above base.
165	--	11	18	3	5	95+	--	--	Oil shale (D) (Gp, 2); 3 ft above base.
165	--	17	21	11	--	40	--	10	Oil shale (D) (Py, 3); 1 ft above base.
164	--	96+	48	9	22	--	--	--	Tuff.
162	--	95+	36	6	8	--	--	--	Do.
161	--	15	17	8	10	82+	--	8	Oil shale (D).
160	--	95+	33	--	8	--	6	--	Tuff.
146	--	6	17	6	4	--	90+	--	Rosette in cavity (Gp, 5).
146	--	7	29	11	10	68	78	3	Residue in cavity (Gp, 5).
133	--	4	15	12	21	57	46	3	Oil shale (D) (Gp, 7).
				Rocks below Mahogany ledge					
131	--	10	44	6	5	76+	--	2	Marlstone (Gp, 3).
131	--	26	14	17	20	85+	--	3	Oil shale (M); in cavity zone.
131	--	38	25	--	--	90+	--	--	Material in cavity (Gp, 2).
130	--	--	--	--	26	80+	6	3	Material in pod.
130	--	--	13	25	27	65	--	5	Marlstone.
126	--	--	13	26	16	50	20	4	Oil shale (D).
120	--	23	21	5	9	60	--	4	Do.
120	--	21	14	12	10	83	3	6	Do.
119	10	12	20	32	--	47	35	--	Cavity filling (Gp, 8).
119	--	9	37	13	6	60	--	3	Marlstone.
119	--	24	18	11	9	80	--	2	Do.
118	--	17	18	6	14	55	--	9	Oil shale (D) (Gp, 12).
117	--	8	14	10	10	62	--	14	Do.
114	--	38	19	27	13	40	--	7	Oil shale (L).
113	24	15	19	16	--	52	--	6	Oil shale (D).
108	--	33	20	24	17	61	--	7	Tuff.
99	12	26	22	21	11	71	--	6	Oil shale (D) (Gp, 4).
96	--	16	35	16	--	28	--	5	Tuff.
94	35	15	25	16	8	--	--	--	Do.
93	13	23	21	22	--	46	--	8	Oil shale (D); 6 ft above base.
93	13	10	20	17	4	59	45	5	Oil shale (D); 3 ft above base.
91	--	28	27	16	--	70	--	8	Oil shale (D) (Gp, 4).
89	--	19	21	9	9	54	--	11	Oil shale (L); 6 ft above base.
89	11	6	22	25	--	62	--	7	Oil shale (L); 4 ft above base.
89	--	--	27	34	--	32	--	9	Oil shale (L); 0.2 ft above base.
88	--	--	22	15	11	85	--	--	Conglomerate, dolomitic.
83	--	--	26	32	13	46	--	8	Oil shale (D).
82	--	3	14	10	--	85+	--	--	Conglomerate, dolomitic.
81	--	--	20	27	--	70	--	6	Oil shale (L).
79	--	--	30	24	--	85+	--	8	Marlstone.
77	--	19	51	13	10	85+	--	8	Oil shale (D).
70	18	8	21	17	11	43	4	6	Oil shale (D); 52.6 ft above unit 49.
64	20	23	26	14	8	40	--	6	Oil shale (D) (Py, 4); 36.1 ft above unit 49.
60	--	80	27	12	22	53	--	--	Marlstone, tuffaceous; 25.6 ft above unit 49.
59	--	92+	38	29	12	--	30	19	Tuff; 24.3 ft above unit 49.
58	--	30	23	16	1	73	--	8	Oil shale (M); 20.9 ft above unit 49.
57	--	75+	36	11	--	65	--	--	Tuff; 19.7 ft above unit 49.
55	--	14	20	12	--	71	--	8	Oil shale (M); 13.4 ft above unit 49.
54	--	31	90	41	--	50	11	6	Tuff; 12.1 ft above unit 49.
52	5	17	10	1	65+	--	--	--	Tuff; 11 ft above unit 49.
51	--	13	17	10	10	81	--	8	Oil shale (L); 9.7 ft above unit 49.
50	47	--	31	17	8	18	25	6	Oil shale (D) (Py, 4); 4 ft above unit 49.
49	--	83	59	14	24	--	13	--	Tuff, a key bed. Tuff 13 of table 10.
48	13	9	33	17	8	66	--	6	Oil shale (D); 2 ft below unit 49.
48	53	7	31	18	7	17	--	5	Oil shale (D); 4.8 ft below unit 49.
48	55	5	31	19	7	12	--	4	Oil shale (D); 5.8 ft below unit 49.
48	19	--	21	13	4	86+	--	5	Oil shale (D); 8.4 ft below unit 49.
48	42	5	30	12	1	45	--	6	Oil shale (M); 8.5 ft below unit 49.
46	31	6	25	18	6	61	--	3	Oil shale (M); 10 ft below unit 49.
44	--	75+	32	19	--	--	--	--	Tuff; 16.5 ft below unit 49.
42	26	8	22	11	--	12	7	11	Oil shale (D) (Py, 5); 20 ft below unit 49.
42	--	23	25	16	--	42	10	9	Oil shale (D) (Py, 5; Gp, 6); 20.6 ft below unit 49.
42	3	18	27	17	10	35	--	8	Oil shale (D) (Py, 4); 21.1 ft below unit 49.
42	33	--	28	17	10	24	12	8	Oil shale (D) (Py, 6); 22.6 ft below unit 49.
42	--	23	24	12	9	49	9	6	Oil shale (D); 23.3 ft below unit 49.
40	24	--	16	17	--	48	8	5	Oil shale (D); 32.4 ft below unit 49.
40	--	15	21	12	11	67	7	15	Oil shale (D); 34.1 ft below unit 49.
39	--	1	11	6	5	96	3	5	Oil shale (D); 37.4 ft below unit 49.
38	--	7	13	5	9	66	11	9	Oil shale (D); 42.4 ft below unit 49.
37	--	41	22	26	6	26	13	6	Tuff; 44.4 ft below unit 49.

TABLE 5.—*Mineral composition, expressed by X-ray peak height in chart units, of rocks in stratigraphic succession from the lower Piceance Creek section* —Continued

Unit sampled	Dawsonite	Analcime	Quartz	Potassium feldspar	Albite	Dolomite	Calcite	Illite	Remarks
PARACHUTE CREEK MEMBER—Continued									
Rocks below Mahogany ledge—Continued									
35	--	9	19	6	7	32	--	13	Oil shale (D); 52.4 ft below unit 49.
35	--	2	21	13	10	21	--	13	Oil shale (D); 52.8 ft below unit 49.
34	36	--	27	30	--	49	--	2	Tuff; 54.0 ft below unit 49.
33	--	10	25	--	9	48	5	11	Oil shale (D).
33	--	8	20	15	7	28	--	10	Oil shale (D); 57.4 ft below unit 49.
32	29	--	31	16	8	22	8	14	Oil shale (D) (Py, 3).
31	--	5	5	2	2	93	--	2	Marlstone; 64.2 ft below unit 49.
30	--	2	17	7	6	53	--	13	Marlstone; 65.2 ft below unit 49.
29	--	9	21	16	7	18	--	10	Oil shale (D); 68.4 ft below unit 49.
28	--	5	23	38	12	--	--	4	Tuff; 72.3 ft below unit 49.
27	6	5	13	9	5	83+	5	4	Oil shale (D); 73.3 ft below unit 49.
26	15	--	50	25	18	57	--	6	Marlstone; 75.3 ft below unit 49.
22	--	5	43	40	--	--	--	6	Tuff.
20	--	9	9	3	3	90+	3	--	Marlstone.
19	--	64	5	11	16	--	--	--	Tuff.
17	--	76 +	9	14	19	--	--	--	Do.
16	--	--	16	10	5	35	--	13	Oil shale (D); 2.7 ft below top.
16	--	15	17	9	8	55	--	11	Oil shale (L); near base.
15	--	5	16	--	9	33	--	13	Oil shale (M).
13	--	--	--	8	3	86 +	11	7	Oil shale (L).
10	--	--	--	6	8	70 +	--	12	Oil shale (D).
8	--	6	6	12	15	15	--	26	Oil shale (D) (Gp, 29).
1	--	12	12	7	10	84	--	5	Do.

TABLE 6.— *Mineral composition, expressed by X-ray peak height in chart units, of rocks in stratigraphic succession from the Rio Blanco section*

[D, dark brown; M, medium brown; L, light brown; Py, pyrite; Cl, chlorite; Gp, gypsum. Leaders (--), not detected]

Unit sampled	Analcime	Quartz	Potassium feldspar	Albite	Dolomite	Calcite	Illite	Remarks
PARACHUTE CREEK MEMBER								
Rocks above Mahogany ledge								
161	35	20	12	9	60	41	10	Oil shale, pyritic (D) (Py, 2).
157	25	15	10	7	50	82	4	Do.
155	25	10	7	7	56	14	4	Oil shale, pyritic (D) (Py, 3).
152	81+	36	23	19	--	--	5	Tuff, micaceous; lowest bed.
151	36	19	12	11	84	--	4	Oil shale, pyritic (D) (Py, 2).
150	83+	41	16	34	--	6	8	Sandstone dike, tuffaceous.
149	24+	17	12	--	80	22	5	Oil shale (D).
148	22	39	11	23	40	39	12	Oil shale (L).
142	6	25	27	80	--	--	11	Tuff pods.
141	11	34	11	18	87 +	19	15	Oil shale (M).
136	31	29	11	34	86 +	--	4	Tuff.
133	32	15	8	8	74	13	5	Oil shale (D).
131	26	15	10	9	85+	25	4	Oil shale (M) (Cl, 3); 3.1 ft above base.
131	9	26	5	3	55	88 +	--	Oil shale (D).
131	28	17	13	10	61	28	5	Oil shale (M).
128	--	13	6	--	85+	--	--	Marlstone.
126	18	15	12	--	72	23	3	Oil shale (D).
125	8	71	20	22	85+	6	13	Marlstone.
120	18	12	9	--	55	72	3	Oil shale (D).
117	41	53	15	26	76	9	7	Marlstone, tuffaceous.
114	6	48	21	22	87+	25	9	Tuff, muscovitic (Cl, 4).
112	7	41	25	19	84+	14	11	Tuff, muscovitic.
110	--	23	23	10	44	23	3	Oil shale, pyritic (D) (Py, 6).
109	40	13	10	8	40	10	5	Oil shale, pyritic (D) (Py, 3).
108	20	15	15	8	74	18	4	Oil shale (M).
105	68	21	17	9	35	7	5	Oil shale (D).
102	88+	25	6	23	--	16	5	Tuff.
100	--	44	12	48	85+	15	11	Marlstone (Cl, 4).
95	16	43	11	--	71	43	3	Oil shale (D).
93	83+	24	7	23	--	24	5	Tuff.
91	--	44	12	18	85+	15	11	Marlstone (Cl, 4).
90	17	86	--	--	44	18	3	Oil shale (D).
87	81+	16	10	15	--	--	5	Tuff.

TABLE 6.—*Mineral composition, expressed by X-ray peak height in chart units, of rocks in stratigraphic succession from the Rio Blanco section* —Continued

Unit sampled	Analcime	Quartz	Potassium feldspar	Albite	Dolomite	Calcite	Illite	Remarks
PARACHUTE CREEK MEMBER—Continued								
Rocks above Mahogany ledge—Continued								
85	7	37	13	22	86	15	13	Marlstone.
74	83+	35	14	10	66	20	17	Tuff, weathered, biotitic.
74	85+	41	23	13	50	22	17	Tuff, fresh, biotitic.
73	10	10	7	6	58	90+	4	Oil shale (M).
71	9	21	22	--	73	33	6	Oil shale (D); 2 ft below top.
71	39	80	10	7	42	--	5	Tuff (Cl, 3).
71	22	14	7	--	75	--	22	Oil shale (M); encloses tuff.
70	13	16	12	1	86+	21	6	Marlstone.
69	28	11	7	13	43	39	3	Oil shale (D).
68	--	14	--	4	90+	--	--	Sandstone.
64	1	--	--	2	91+	70	--	Do.
63	10	18	18	--	86	31	--	Oil shale (L).
59	38	21	22	18	32	4	6	Tuff (Cl, 5; Gp, 3).
Mahogany ledge								
58	44	13	5	9	82+	--	4	Oil shale (L).
57	4	5	--	--	90+	70	--	Clay bed (Cl, 31).
55	--	26	--	3	90+	--	--	Marlstone (Cl, 30).
53	78+	20	10	10	30	--	--	Tuff (Cl, 30).
52	20	24	9	14	86	--	8	Marlstone (Cl, 8).
51	13	64	35	39	43	--	7	Tuff, muscovitic (Cl, 9).
49	85 +	37	7	34	40	--	--	Tuff (Cl,3).
47	39	23	--	75 +	27	--	4	Sandstone dike (Cl, 7).
46	78+	22	10	11	--	--	5	Tuff, weathered.
46	78+	17	14	9	--	--	--	Tuff, fresh. Mahogany marker.
44	9	26	22	18	90+	--	9	Marlstone.
43	20	11	10	10	59	22	3	Oil shale (D). Mahogany bed.
42	12	7	2	4	95+	--	2	Dolomite
41	20	14	--	8	96	21	5	Oil shale (D).
40	15	24	10	17	95+	3	13	Dolomite.
37	--	30	11	20	86+	19	10	Oil shale (D); 15.9 ft above base.
37	8	16	--	16	59	41	5	Oil shale (D); 10.6 ft above base.
36	13	14	9	16	67	18	--	Oil shale (D)
34	20	10	--	12	79	--	4	Oil shale (D); uppermost bed.
34	14	11	10	--	95+	9	3	Oil shale (D); lowermost bed.
33	65	38	--	53	33	--	39	Tuff, biotitic.
Rocks below Mahogany ledge								
31	89+	20	16	77	74	--	3	Tuff.
29	5	11	--	7	90+	3	--	Dolomite.
27	75+	36	--	22	--	--	--	Sandstone, tuffaceous (Gp, 4).
25	2	4	--	7	90+	3	--	Sandstone.
23	80+	20	18	22	--	--	5	Tuff.
22	31	18	17	17	80	32	7	Marlstone.
21	12	22	12	11	86+	--	4	Do.
20	87+	45	12	45	--	--	--	Tuff.
17	25	17	31	25	58	6	6	Marlstone.
16	--	37	25	18	74	82	4	Sandstone.
15	24	23	30	22	84+	--	5	Marlstone, tuffaceous; 25 ft above base.
15	42	16	17	28	73	18	5	Marlstone; 5 ft above base.
15	55	11	23	29	70	--	4	Marlstone, tuffaceous; at base of unit.
14	28	11	15	15	37	--	--	Cavity filling (Cl, 8; leonhardite, 23).
14	11	24	12	17	--	--	--	Noddule (Gp, 55).
14	49	14	27	25	73	--	--	Marlstone (Py, 2).
14	22	6	--	7	--	--	--	Concretion, pyritic (Py, 27).
14	35	22	16	19	52	--	8	Marlstone (Gp, 17).
14	10	19	--	14	--	--	--	Concretion, pyritic (Py, 5; Gp, 29).
14	--	--	--	--	--	--	--	Concretion, pyritic (Py, 17; szmolnokite, 28).
14	32	16	18	26	52	--	4	Marlstone (Gp, 21).
12	8	10	13	11	59	56	--	Marlstone, fossiliferous (insects).
12	7	13	14	13	75	3	--	Marlstone.
10	16	8	7	7	74+	--	5	Do.
10	47	17	18	14	61	--	5	Tuff.
9	10	31	24	12	76	--	5	Siltstone, tuffaceous.
9	12	27	20	12	85+	--	7	Marlstone (Cl, 3).
8	12	4	--	6	84+	4	--	Tuff (Cl, 17).
1	4	28	32	14	88+	--	3	Marlstone (Cl, 3).

TABLE 7.—*Mineral composition, expressed by X-ray peak height in chart units, of oil shale and marlstone from the three measured sections*

[Numbers in parentheses indicate number of samples]

Mineral	Marlstone (60)		Light-brown oil shale (17)		Medium-brown oil shale (33)		Dark-brown oil shale (86)	
	Modal class	Median class	Modal class	Median class	Modal class	Median class	Modal class	Median class
Analcime	1-10 (20)	11-20	1-10 (3)	11-20	11-20 (11)	11-20	21-30 (29)	11-20
Quartz	11-20 (23)	21-30	11-20 (7)	11-20	11-20 (24)	11-20	11-20 (47)	11-20
Potassium feldspar	11-20 (20)	11-20	1-10 (8)	11-20	11-20 (16)	11-20	11-20 (42)	11-20
Albite	1-10 (9)	11-20	1-10 (8)	1-10	1-10 (18)	1-10	1-10 (50)	1-10
Dolomite	81-90 (23)	71-80	81-90 (5)	61-70	81-90 (7)	61-70	51-60 (14)	51-60
Calcite	0 (34)	0	0 (11)	0	0 (15)	1-10	0 (35)	1-10
Illite	1-10 (42)	1-10	1-10 (12)	1-10	1-10 (26)	1-10	1-10 (71)	1-10

Some albite was detected in about 85 percent of the 196 samples of oil shale and marlstone. Albite peaks in about half the samples of oil shale have heights in the modal class (peaks of 1–10 chart units). The modal class of peak heights for albite is the same in the marlstone as in the oil shale, but the range of all values is greater in the marlstone, as indicated by only nine of 60 peaks being within the modal class and by the median value lying in the class of 11–20 chart units. Most of the sodium feldspar is low-structured albite (Ab_{95-100}) as determined by the X-ray technique of Wright (1968, fig. 3). Low-structured albite is considered to be of low-temperature origin, and it has a high degree of order of the silicon and aluminum atoms in the structure.

Small amounts of illite occur in many of the samples, and chloritic material occurs in a few of the samples.

Pyrite occurs as tiny disseminated grains and streaks in many rocks—most commonly, the dark oil shales.

Small amounts of some sulfate minerals derived from the weathering of pyrite and other minerals occur mostly as coatings along bedding planes or as fillings in fractures, or even as blooms of efflorescent salts. The most common of these minerals is gypsum ($CaSO_4 \cdot 2H_2O$), which occurs chiefly as thin white coatings along bedding planes. The coatings of gypsum are especially abundant in the outcrops along lower Piceance Creek. Other sulfate minerals detected by X-ray diffraction analysis are szomolnokite ($FeSO_4 \cdot H_2O$), starkeyite ($MgSO_4 \cdot 4H_2O$), and bloedite ($MgSO_4 \cdot Na_2SO_4 \cdot 4H_2O$) (B.M. Madsen, written commun., 1968).

VERTICAL VARIATION IN COMPOSITION

Data compiled in tables 4, 5, 6, and 7 characterize the composition of the mineral fraction of units a few inches thick of the generally laminated oil shale and marlstone taken from various stratigraphic intervals in the three measured sections. Further detailed study of some differing units of these rocks was undertaken to determine how similar a randomly sampled inch or two of rock is to the next few inches or feet above or below.

For this study, selected blocks of rocks were sawed, and samples were obtained with the use of a dental drill. Powdered samples thus obtained were pelletized and were used to form a veneer of sample on a backing of powdered cellulose. In the descriptions below, the letter and number symbols in parentheses refer to colors in the standard "Rock-Color Chart" by Goddard and others (1948).

FOSSILIFEROUS OIL SHALE AND MARLSTONE, PIPELINE SECTION

A stratigraphic thickness of 12.15 cm of laminated light-brown oil shale and marlstone rich in insect fossils was selected for detailed study from unit 197 in the pipeline section. The slab of rock, shown in figure 9, is 20 cm wide and has light laminae that are yellowish gray (5*Y* 7/2) to light gray (*N* 7) alternating with dark laminae that are light olive gray (5*Y* 5/2) to medium gray (*N* 5). Each sample consists of a series of extremely thin light and dark laminae, but each sample has a distinctly different color when compared with the samples above and below (fig. 10).

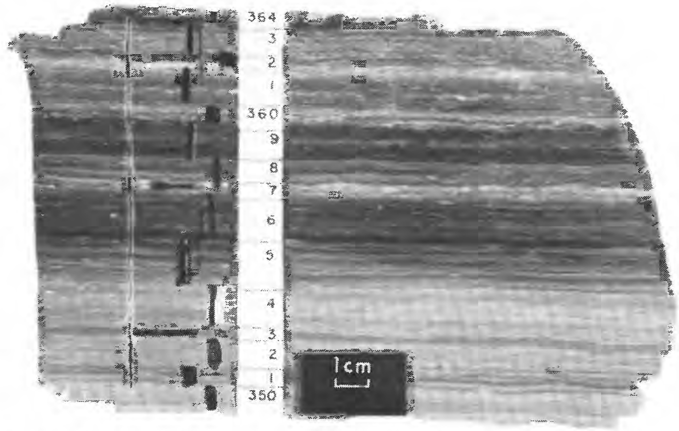


FIGURE 9.—Fossiliferous laminated oil shale and marlstone from the pipeline section (unit 197.) Dark spots show where samples were taken. Numbers are sample numbers used in figure 10.

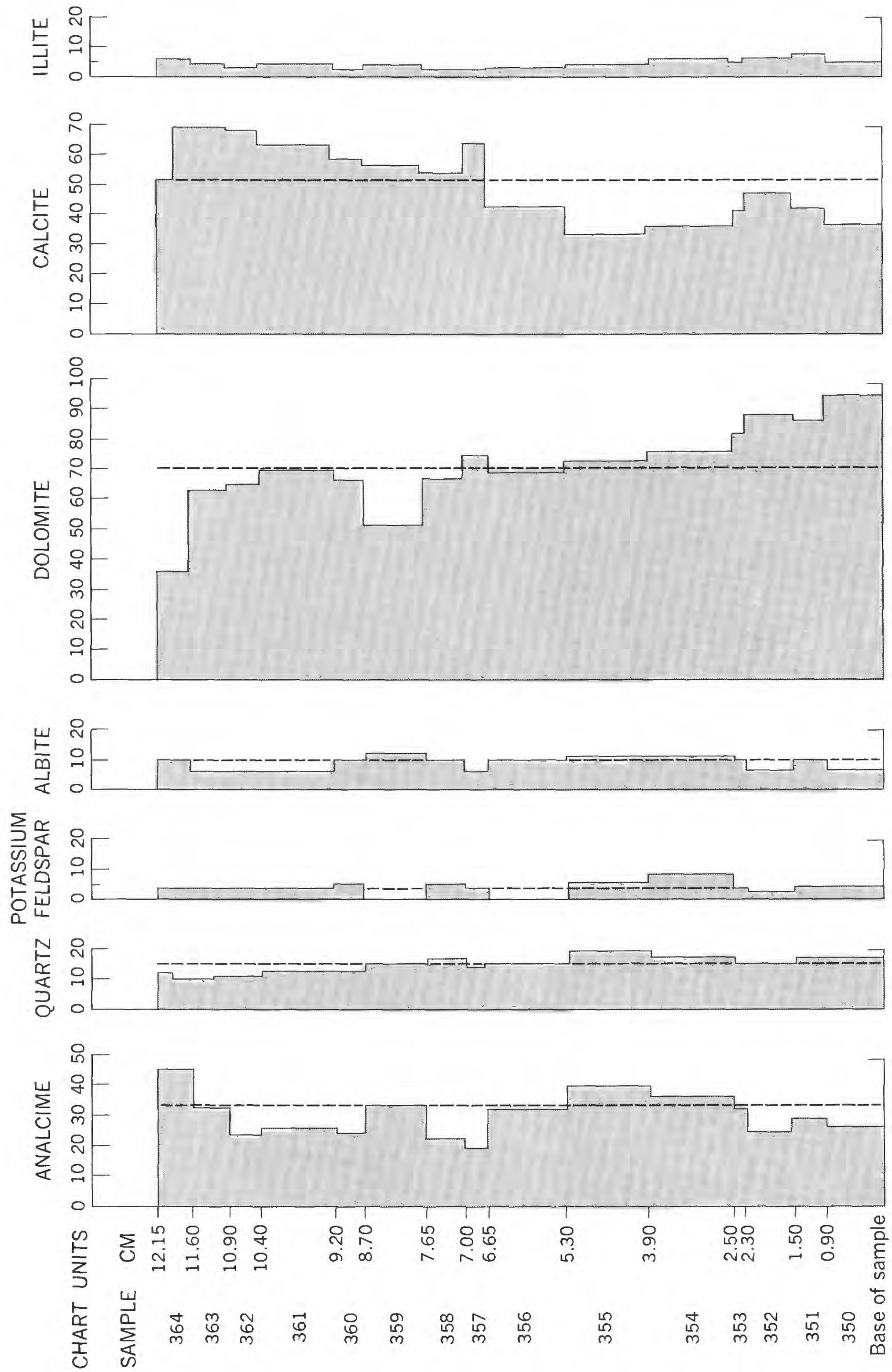


FIGURE 10.—Mineral composition of fossiliferous laminated oil shale and marlstone from the pipeline section (unit 197), as expressed by X-ray peak height in chart units. Dashed line indicates arithmetic average of values for each mineral from composite sample.

TABLE 8.—*Mineral composition, expressed by X-ray peak height in chart units, of a sequence of marlstone and medium-brown oil shale from the pipeline section (unit 218)*

[D, dolomite; C, calcite]

Thickness (cm)	Number of samples: Dark layers D>C	Dark layers C>D	Dark layers Total	Light layers D>C	Light layers C>D	Light layers Total	Total	Arithmetic average of peak height: Analcime	Quartz	Potassium feldspar	Albite	Dolomite	Calcite	Illite
26.7	3	3	6	8	2	10	16	28	13	5	5	69	65	3
7.8	0	3	3	0	2	2	5	20	13	3	4	58	80	3
15.1	3	1	4	4	1	5	9	19	13	3	4	74	58	3
21.3	0	8	8	2	13	15	23	20	11	4	4	69	74	3
1.9	1	0	1	3	0	3	4	20	14	4	5	81	69	4
2.0	0	1	1	0	2	2	3	22	12	3	3	73	87	3
4.2	5	1	6	5	0	5	11	24	14	4	6	82	69	3
10.4	8	1	9	0	9	9	18	14	10	4	4	84	75	0

The thickest individual lamina in this slab is about 1 mm thick, but commonly the total thickness of three or four pairs of light and dark laminae is only 1 mm. Even some of the thinnest laminae can be traced laterally across the entire slab.

Clearly visible in figure 9 are structural features that Bradley (1931, p. 29) called "loop bedding." In these, the normally even and regular lateral course of the laminae in thin sequences generally a few millimeters thick is interrupted irregularly by constriction of some or all of the layers. In the short interval of constriction, the inner laminae of the sequence commonly are pinched off, but the upper and lowermost laminae are not. These features are more common in the oil shale than in the marlstone, as noted by Bradley (1931, p. 29). The greater abundance of these features in rocks rich in organic matter suggests that they may be related to the algal life in the lake.

The composition of the samples is shown in figure 10. Major minerals are dolomite and calcite that are in association with analcime, quartz, feldspar, and illite. The X-ray data indicate that the upper half of the slab contains more calcite and less dolomite than the lower half. No other differences in mineral composition are apparent, but the upper half of the slab seems to be darker. The composition of a composite channel sample of the entire slab is shown by the broken lines in figure 10.

MARLSTONE AND MEDIUM-BROWN OIL SHALE, PIPELINE SECTION

A stratigraphic thickness of 96.8 cm of marlstone and medium-brown oil shale from unit 218 in the pipeline section was studied in a series of slabs of rock 5–22 cm wide. This sequence of rocks is well laminated, and as in the slab described above, many individual laminae are no more than 0.5 mm thick. The lightest colored laminae in this sequence are yellowish gray (5*Y* 7/2) to grayish yellow (5*Y* 8/4). The medium-colored laminae are light olive gray (5*Y* 6/1 and 5*Y* 5/2) to dark yellowish brown (10*YR* 4/2). The dark laminae contain the most organic matter and range from olive gray 5*Y* 4/1 and 5*Y* 3/2) through dusky yellowish brown (10*YR* 2/2) to brownish black (5*YR* 2/1).

The mineral composition of the suite of 89 samples is summarized in table 8, which emphasizes some of the characteristics of these rocks rich in dolomite and calcite. A major feature of these rocks is the stratigraphic variation in content of calcite and dolomite; groups of layers rich in calcite alternate with groups rich in dolomite. There is no apparent correlation of the predominance of calcite or dolomite with either light or dark layers. The relative content of the other minerals does not vary greatly.

OIL SHALE FROM THE MAHOGANY LEDGE, LOWER PICEANCE CREEK SECTION

A slab from a 20.6-cm-thick sequence of oil shale from the Mahogany ledge was selected for study from unit 161 in the lower Piceance Creek section. This sequence of rock, shown in figure 11, is well laminated, but compared with the rock shown in figure 9, the laminae in this sequence are more clearly defined and form small units of rock with more distinctly contrasting color. As in the other rocks examined in detail the individual laminae are extremely thin. This slab is generally darker than the others described in this part of the report, mostly because these rocks are richer in organic matter. The lightest laminae in the oil shale are light brown (5*YR* 6/4); the intermediate-colored laminae are moderate brown (5*YR* 4/4) to dark yellowish brown (10*YR* 2/2) to blackish red (5*R* 2/2). The tuff at the base of the slab consists of two phases differing in color and texture. The lower, coarser grained part (sample 200) is moderate brown (5*YR* 4/4), and the upper, finer grained part (sample 201) is pale yellowish brown (10*YR* 6/2). The upper part easily could be mistaken for marlstone in a casual examination.

The composition of 20 samples from this sequence is shown in figure 12. Major minerals in the oil shale are dolomite and calcite, but in this sequence the dolomite peaks in general have twice the heights of the calcite peaks. Analcime, quartz, potassium feldspar, and albite are detectable in every sample. Small amounts of illite are detectable in most samples.

The tuff has been altered to a rock consisting mostly of analcime and quartz. The total amount of feldspar probably is about equal in each tuff layer, but the coarser grained layer contains only albite, and the finer grained layer contains both potassium feldspar and albite.

MASSIVE MARLSTONE FROM THE MAHOGANY LEDGE, LOWER PICEANCE CREEK SECTION

The entire 31.25-cm stratigraphic thickness of massive pale-yellowish-brown (10*YR* 6/2) marlstone of unit 166 was studied in two slabs from the Mahogany ledge of the lower Piceance Creek section. Some discontinuous, undulating thinly laminated brownish-black (5*YR* 2/1) lenses occur throughout the bed.

The mineral composition of the bed is shown in figure 13. The rock is composed chiefly of calcite and dolomite, with dolomite predominating only in the thin discontinuous dark layers. The composition of the bed is remarkably uniform, except for a slight decrease upward in the content of analcime and for the great variation of analcime, dolomite, and calcite in the thin dark bed (sample 5, fig. 13).

MARLSTONE AND LAMINATED OIL SHALE FROM THE MAHOGANY LEDGE, RIO BLANCO SECTION

A slab from a 9.5-cm-thick sequence of marlstone and laminated oil shale in the Mahogany ledge was selected for study from unit 44 in the Rio Blanco section. This sequence of rock is shown in figure 14. The lower 14 mm consists of thinly laminated oil shales. The lightest layers are yellowish gray (5*Y* 7/2), and

FIGURE 11.—Laminated oil shale from the Mahogany ledge in the lower Piceance Creek section (unit 161.) Dark spots show where samples were taken. Numbers are sample numbers used in figure 12.

the darkest layers are dusky yellowish brown (10*YR* 2/2). The next 54 mm of pale-yellowish-brown (10*YR* 6/2) marlstone consists of five massive beds in which the lower parts are coarser grained and slightly darker than the upper parts. Each of the five beds is separated by a few thin undulating dark laminae that appear to have more organic material than the rock above and below. Above the five massive beds are three thinner, but massive, beds separated by dark layers that are thicker than those in the beds below. These three beds have an aggregate thickness of 14 mm. The uppermost 13 mm of the sample consists chiefly of thinly laminated beds of marlstone that range from yellowish gray (5*Y* 8/1) to light olive gray (5*Y* 5/2).

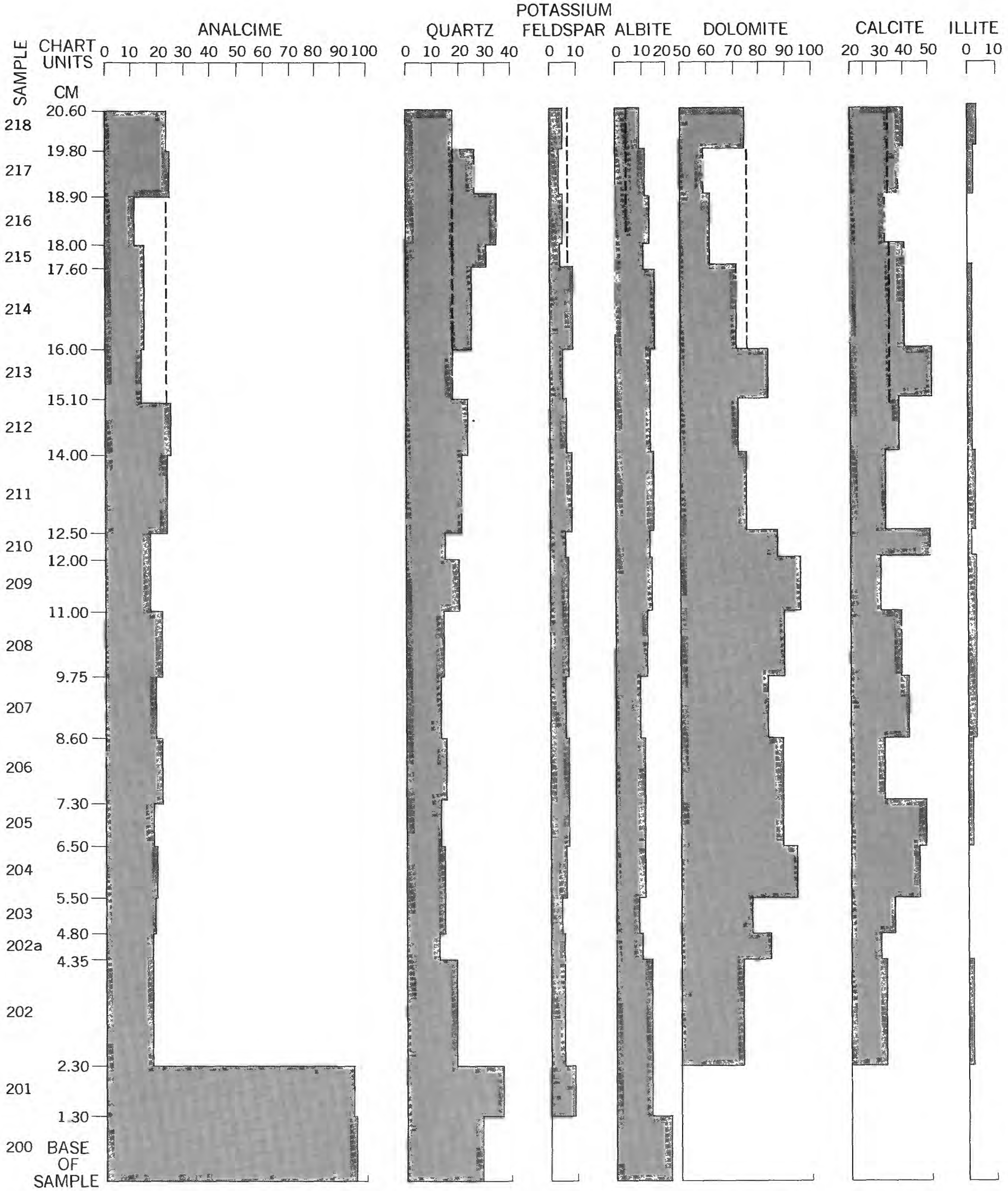


FIGURE 12.—Mineral composition of laminated oil shale from the Mahogany ledge in the lower Piceance Creek section (unit 161), as expressed by X-ray peak height in chart units. Dashed line indicates arithmetic average of values for each mineral in a composite sample of units 202-218.

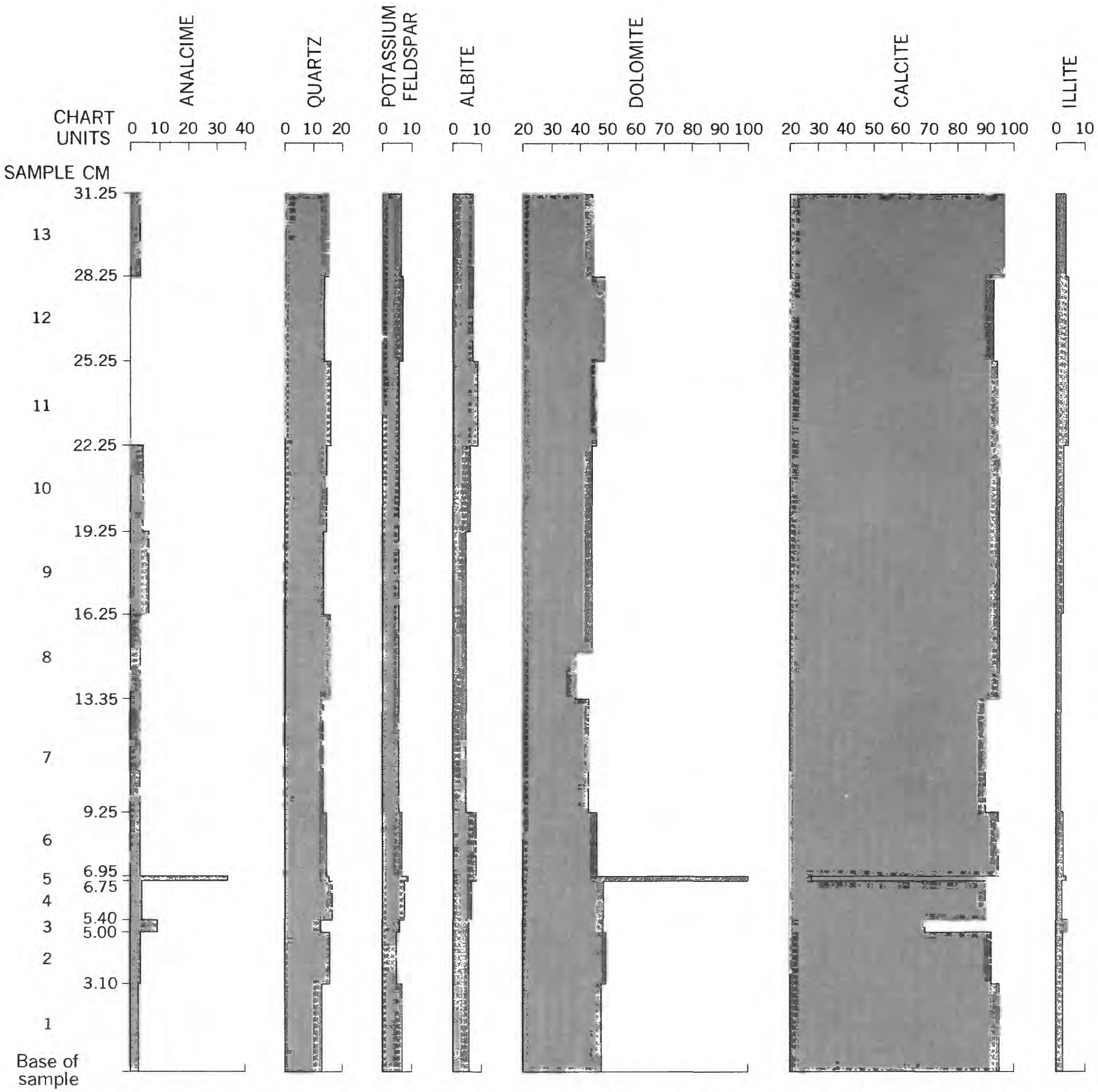


FIGURE 13.—Mineral composition of massive marlstone from the Mahogany ledge in the lower Piceance Creek section (unit 166), as expressed by X-ray peak height in chart units.

The mineral composition of these layers is shown in figure 15. As in most of the rocks, the commonly detected minerals include dolomite, quartz, analcime, potassium feldspar, albite, and illite. Calcite is conspicuously absent, in marked contrast to the marlstone and oil shales in the comparable stratigraphic position beneath the Mahogany marker on lower Piceance Creek. The laminated rock in the lower 14 mm of the slab contains a little more feldspar and a little less dolomite than some of the oil shales studied. The composition of the marlstone and oil shale in the uppermost 13 mm of the slab varies widely.

The middle 54 mm of the slab contains beds considerably different than many noted elsewhere in this study. The massive nature of the beds and the variation in grain size, coarser on the bottom and finer on the top, lend a distinctive appearance of "graded bedding" to this unit of rock. Data in figure 15 indicate that the coarser grained part of the beds contains more analcime and quartz, and less dolomite, than the finer grained part. The thin dark interlayers generally are more distorted than many other layers and contain more dolomite—and probably more organic matter—and less analcime than the adjacent layers.

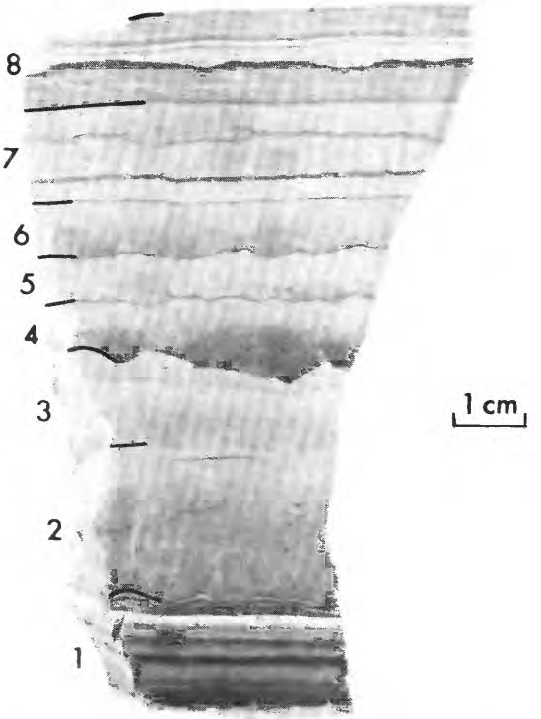


FIGURE 14.—Marlstone and laminated oil shale from the Mahogany ledge in the Rio Blanco section (unit 44). Numbers indicate position of composite samples shown in figure 15.

LATERAL VARIATION IN COMPOSITION

MEDIUM-BROWN OIL SHALE, PIPELINE SECTION

Lateral variation in composition of a sequence of medium-brown oil shale about 3 inches thick that lies 3.1 feet below the top of unit 221 in the pipeline section was studied in a series of samples collected at 20-foot intervals along 240 feet of continuous exposure. The north end of the sequence is about 40 feet south of a cattleguard. The rock is thinly laminated; the lightest layers are pale yellowish brown (10*YR* 6/2), and the darkest layers are brownish gray (5*YR* 4/1).

The mineral composition of the 10 samples is shown in figure 16. The minerals detected include dolomite, calcite, analcime, quartz, illite, potassium feldspar, and albite. Dolomite is more abundant than calcite in all the samples. These data indicate a lateral consistence in composition.

DARK, PYRITIC OIL SHALE, RIO BLANCO SECTION

Lateral variation in mineral composition of a well-exposed blue-gray-weathering dark pyritic oil shale was studied in a suite of 37 samples collected at 100-foot intervals along the continuous exposures of unit 155 in the Rio Blanco section. The samples were collected from the middle of the 0.3-foot-thick bed that is exposed as a rounded ledge 22.3 feet above the top of the westernmost roadcut in the Rio Blanco section (fig. 7).

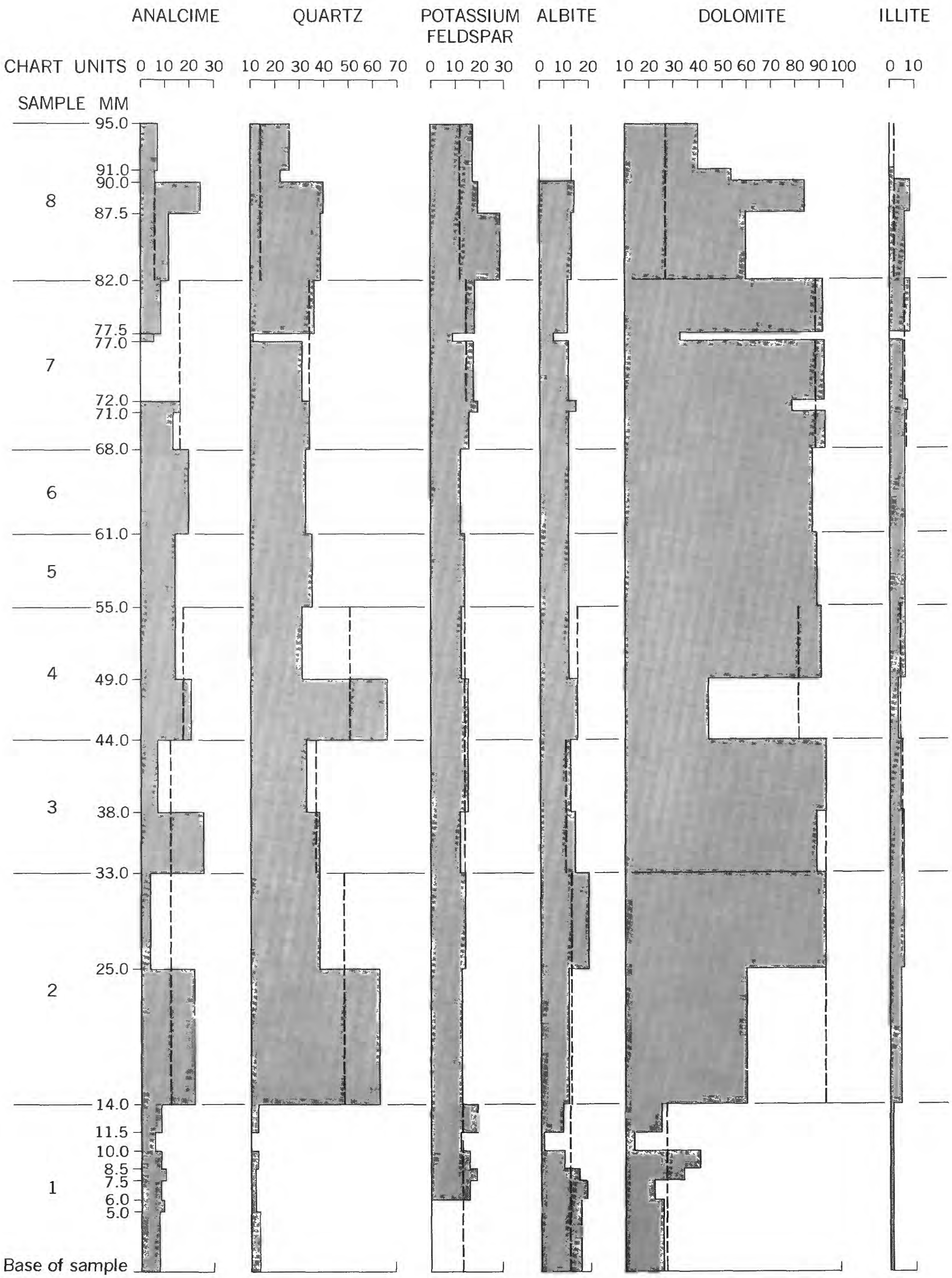
The blue-gray weathered coating is very thin. The rock is laminated on close inspection, but it has a massive appearance because it is so dark—dark gray (*N* 3) to grayish black (*N* 2). The only mineral visible to the unaided eye is pyrite, which is disseminated throughout the bed. The pyrite is most easily seen on fractures crossing the planes of lamination at low angle.

The mineral composition of these samples is shown in figure 17; the samples are numbered in horizontal sequence eastward from sample 1. Dolomite, analcime, quartz, potassium feldspar, albite, calcite, illite, and pyrite were detected. A comparison of the range and arithmetic average of the mineral content of the various samples indicates a normal distribution of the values; that is, the data suggest a laterally uniform composition for this bed.

DAWSONITIC ROCKS

Dawsonite ($NaAl(OH)_2CO_3$) has been described from drill cores in the Piceance Creek basin by Smith and Milton (1966), and the potential resources of dawsonite have been discussed by Hite and Dyni (1967). In November 1966, we found dawsonite during X-ray study of medium- and dark-brown oil shales in the measured section on lower Piceance Creek. The dawsonite occurs in scattered samples from a stratigraphic interval of about 370 feet—from

FIGURE 15.—Mineral composition of marlstone and laminated oil shale from the Mahogany ledge in the Rio Blanco section (unit 44), as expressed by X-ray peak height in chart units. Dashed line indicates arithmetic average of peak height in each composite sample. Interval of composite sample is shown by horizontal line and is numbered as shown in figure 14.


ANALCIME
QUARTZ
POTASSIUM FELDSPAR
ALBITE
DOLOMITE
ILLITE
CHART UNITS
0 10 20 30
10 20 30 40 50 60 70
0 10 20 30
0 10 20
10 20 30 40 50 60 70 80 90 100
0 10
SAMPLE MM
95.0
91.0
90.0
87.5
82.0
77.5
77.0
72.0
71.0
68.0
61.0
55.0
49.0
44.0
38.0
33.0
25.0
14.0
11.5
10.0
8.5
7.5
6.0
5.0
8
7
6
5
4
3
2
1
Base of sample

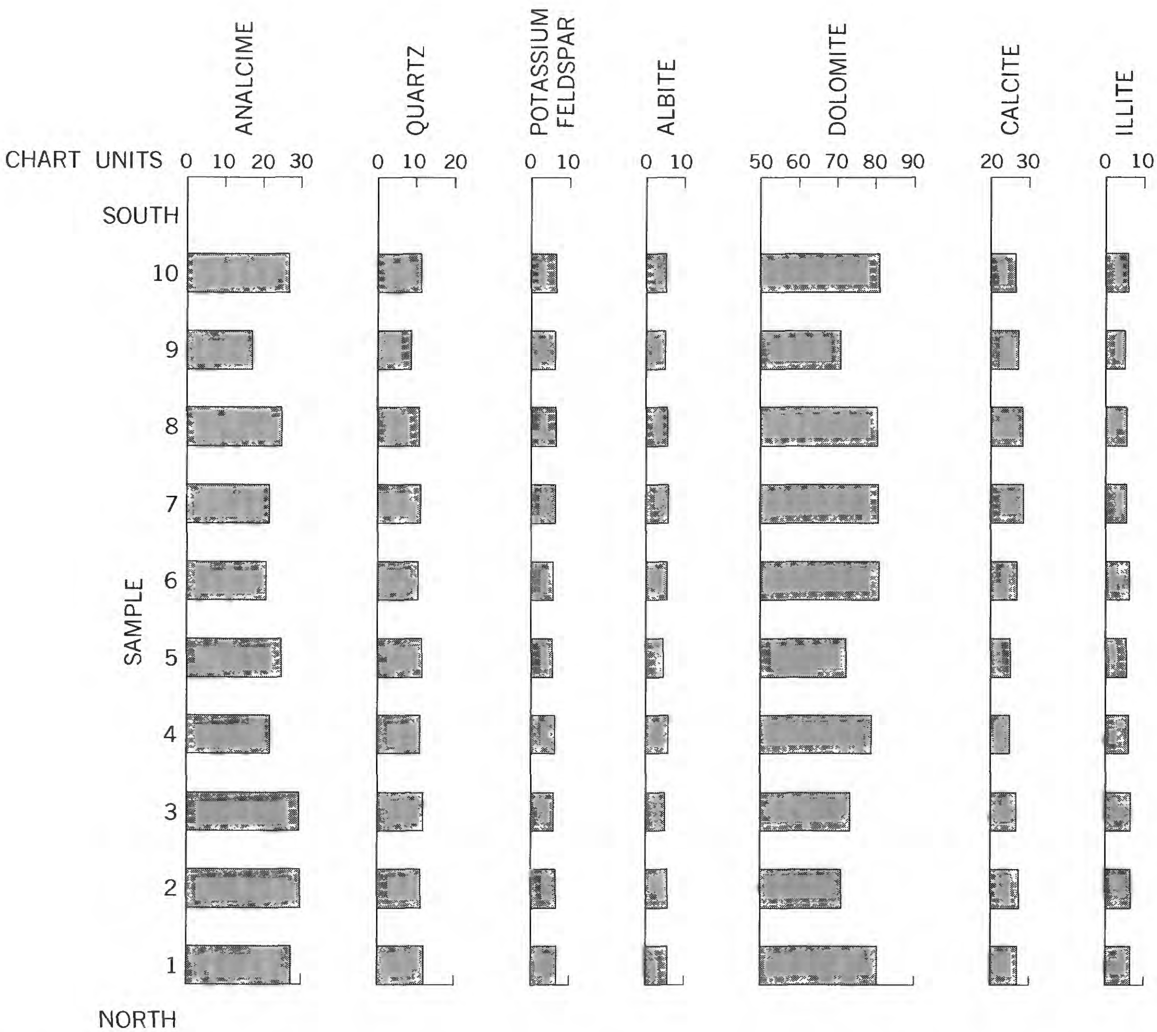


FIGURE 16.—Lateral variation in mineral composition of medium-brown oil shale from the pipeline section (unit 221), as expressed by X-ray peak height in chart units. Horizontal sample interval is 20 feet.

about 200 feet above the base of the Parachute Creek Member upward to within about 70 feet of the base of the Mahogany ledge.

A dawsonite-rich zone about 45 feet thick occurs about 50 feet above the base of the R-5 zone (fig. 6). This zone has been traced updip from its emergence on lower Piceance Creek for about 1.5 miles northwest to the edge of the plateau overlooking the White River (fig. 3). As a result of this work, several tons of rock from this zone were quarried for further study by the U.S. Bureau of Mines. The rock was taken from the exposures at the level of the Piceance Creek road (fig. 4) in the SE¼SW¼ sec. 11, T. 1 N., R. 97 W. (J. W. Smith, written commun., 1967).

A suite of 54 samples consisting of 47 dark- and seven medium-brown oil shales was studied in detail, and the mineral composition is summarized in table 9. Quartz, potassium feldspar, dolomite, and dawsonite occur in all the samples, and illite occurs in 53 samples. Albite and analcime, however, occur in only about half the samples; and pyrite and calcite, in only about one-fourth.

X-ray analysis of the 54 samples of dawsonitic rock from lower Piceance Creek shows that dawsonite content increases as quartz content increases but varies inversely with analcime content (fig. 18). Hay (1970, p. 254) reported similar relations from drill cores of rocks from the deeper parts of the basin; he suggested that dawsonite and quartz could have formed from analcime under a high partial pressure of carbon dioxide, determined by equilibrium with nahcolite, according to the following reaction:

$$NaAlSi_2O_6 \cdot H_2O + CO_2 \rightarrow 2SiO_2 + NaAl(OH)_2CO_3$$

analcime $\rightarrow$ quartz + dawsonite

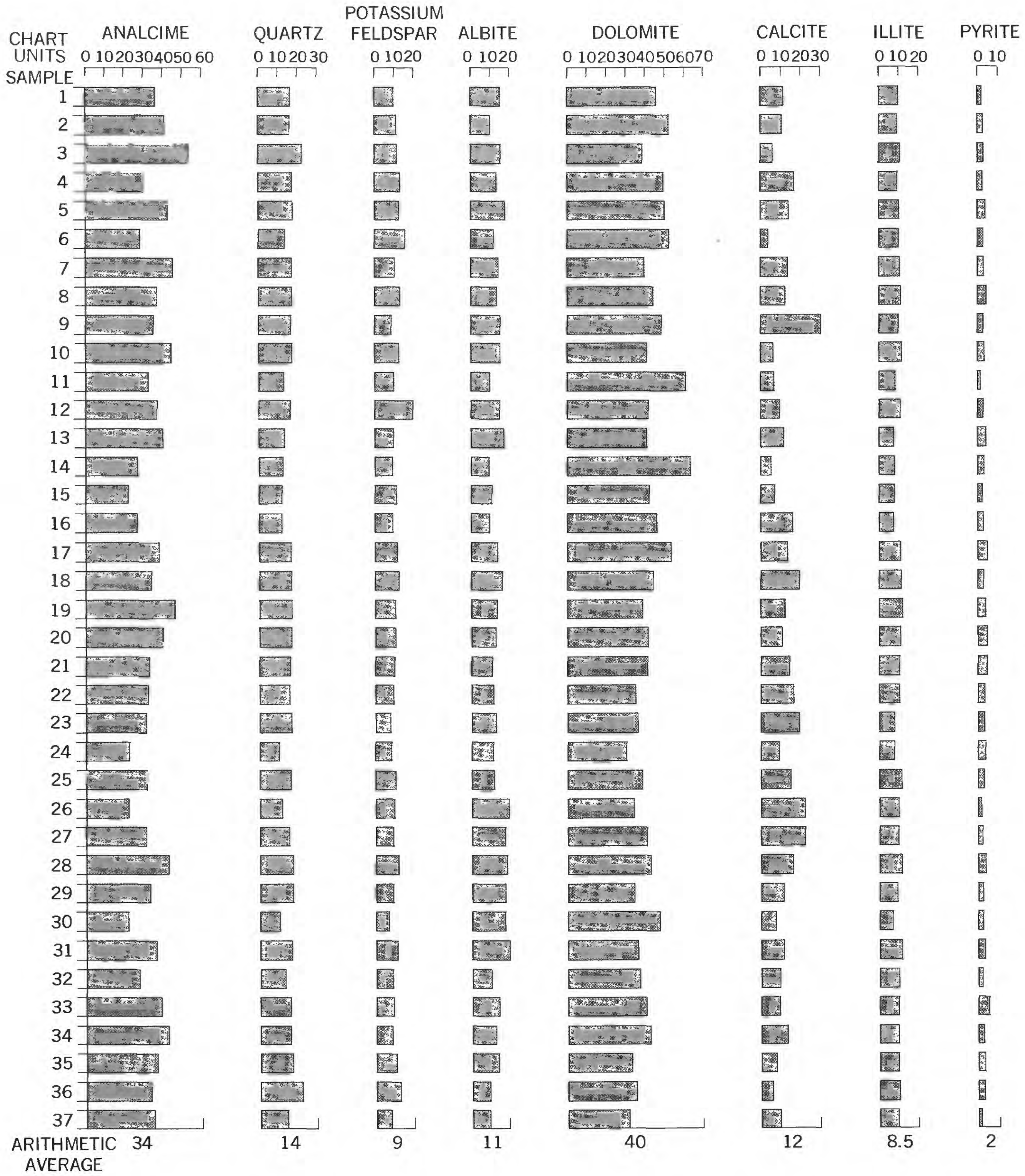


FIGURE 17.—Lateral variation in mineral composition of dark pyritic oil shale from the Rio Blanco section (unit 155), as expressed by X-ray peak height in chart units. Horizontal sample interval is 100 feet, beginning on the west with sample 1. Locality is shown in figure 7.

TABLE 9.—*Mineral composition, expressed by X-ray peak height in chart units, of 54 dawsonitic rocks exposed on lower Piceance Creek.*

Mineral	Number of samples	Peak height	
		Range	Arithmetic average
Dawsonite	54	3-90	34
Dolomite	54	5-85	40
Quartz	54	8-40	25
Potassium feldspar	54	6-35	13
Illite	53	2-11	6
Albite	34	4-25	9
Analcime	32	4-34	15
Pyrite	15	1-8	4
Calcite	14	4-18	10

In a detailed investigation of the composition of analcime by the X-ray method of Saha (1961) in 91 samples of oil shale and tuff with and without dawsonite, we (Brobst and Tucker, 1972) found that analcime in rocks containing dawsonite has a higher silicon to aluminum ratio than analcime in rocks containing no dawsonite. Data from this study, shown in figure 19, indicate that analcime in dawsonitic rocks is more siliceous and less aluminous than analcime in rocks without dawsonite. This relation and the relatively more abundant quartz in the dawsonitic rocks suggest that aluminum and silicon made available in the diagenetic alteration and breakdown of analcime were utilized in the formation of dawsonite and quartz.

Figure 18 shows that most of the peak heights of albite lie between 0 and 15 chart units regardless of dawsonite content. The albite-analcime relation in dawsonitic rocks is plotted in figure 20. There is no apparent relation between the contents of albite and analcime. A similar result is seen in figure 21, where the data for the same pair of minerals are plotted for 190 samples of oil shale and marlstone that contain no dawsonite.

Compared with the nondawsonitic oil shales and marlstones, the dawsonitic rocks contain more quartz, less analcime and dolomite, rarely any calcite, slightly smaller amounts of feldspar, and about the same amount of illite.

VERTICAL VARIATION IN COMPOSITION DAWSONITIC, PYRITIC OIL SHALE, LOWER PICEANCE CREEK ROAD

A stratigraphic thickness of 17.0 cm of dusky-yellowish-brown (10*YR* 2/2) to brownish-black (5*YR* 2/1) dawsonitic, pyritic oil shale was selected for study in a pair of slabs from the cut made by the U.S. Bureau of Mines along the lower Piceance Creek road (SE¼SW¼ sec. 11, T. 1 N., R. 97 W.). The top of the interval selected begins 4 feet below the base of a tuff which is well exposed near the top of the cut. Shiny black scales of gar pike are abundant in this sequence of rocks. Laminae are laterally persistent in the

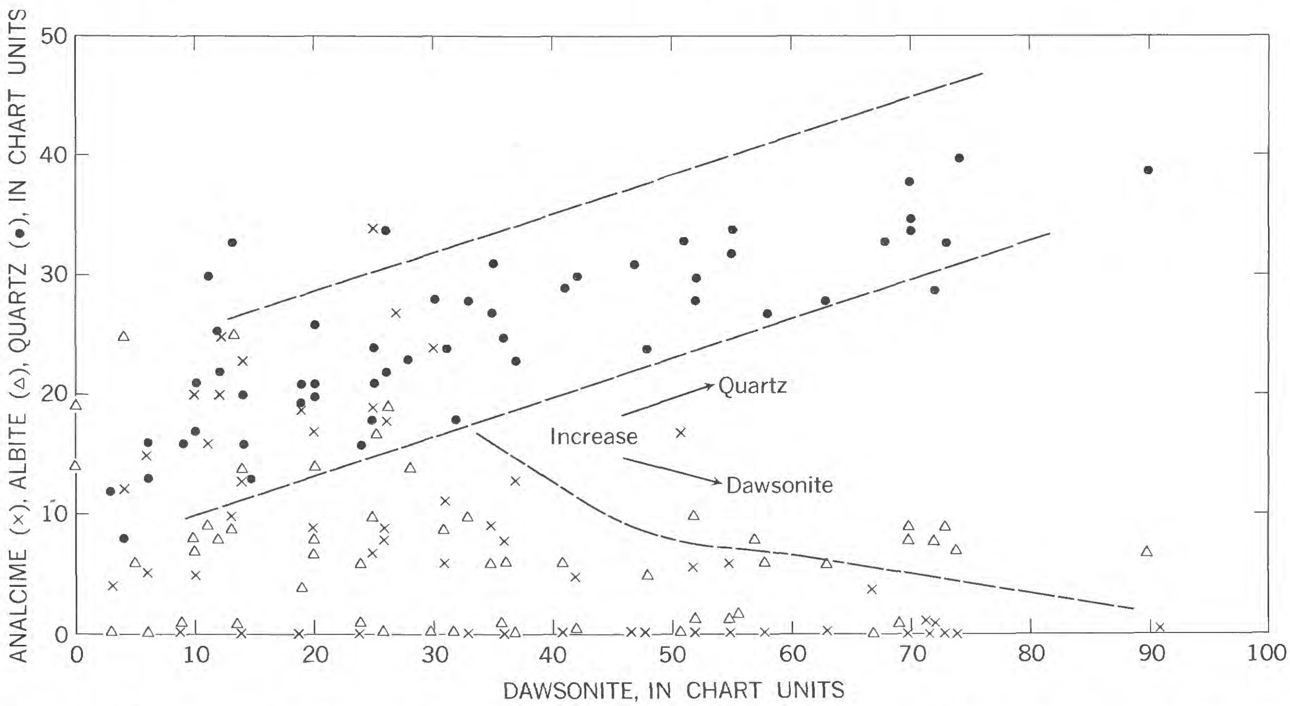


FIGURE 18.—Abundance of analcime, albite, and quartz as a function of abundance of dawsonite in samples from the Parachute Creek Member.

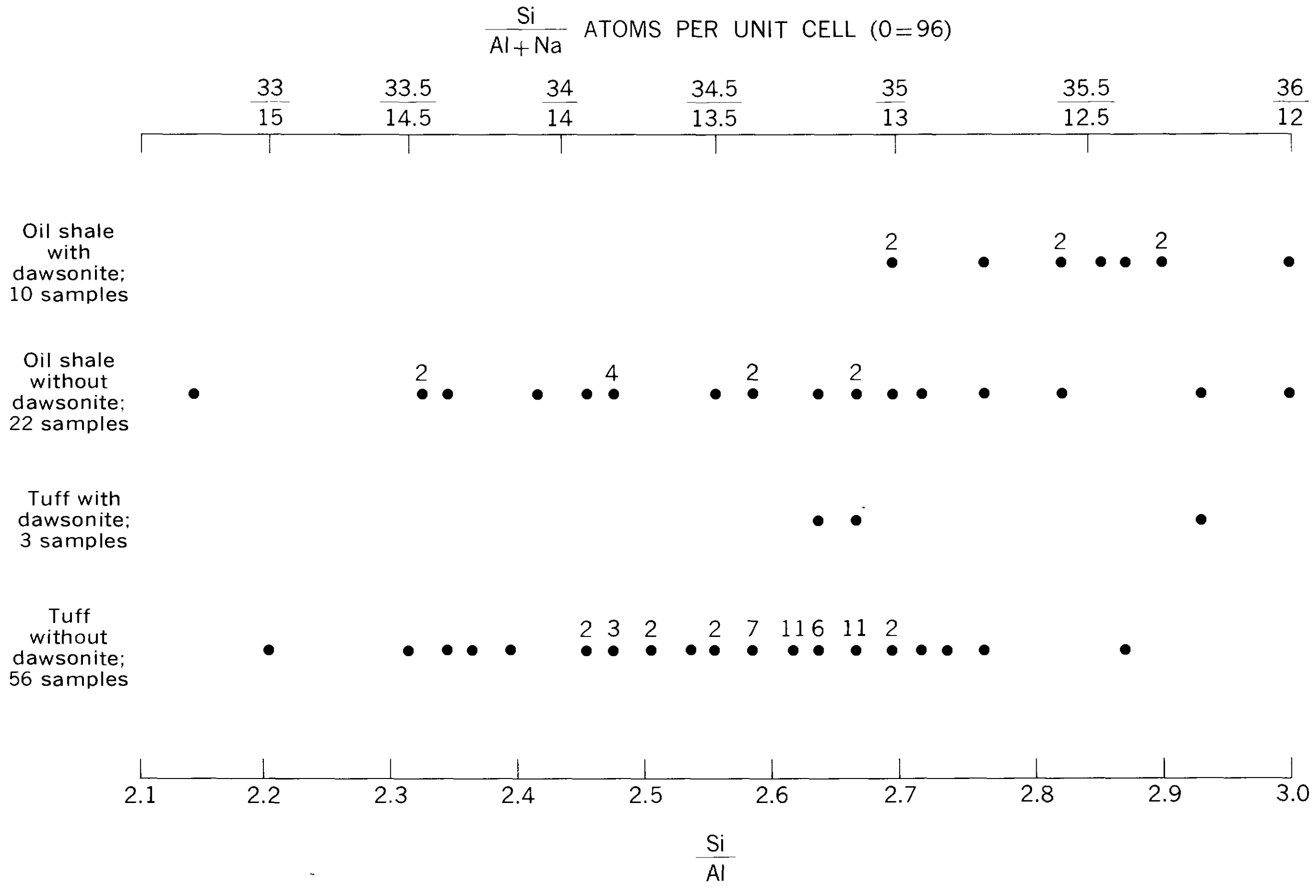


FIGURE 19.—Ratios of silicon to aluminum and of silicon to aluminum plus sodium in analcime from 91 samples with and without dawsonite, Parachute Creek Member. Numbers next to dots indicate number of samples plotted at that position.

rocks, but they are seen only on close inspection because the color contrast of adjacent layers is slight, because of the abundance of organic matter.

The mineral composition of these rocks is shown in figure 22. The data show a broad range in peak heights of dawsonite—14–71 chart units. Dawsonite content generally decreases upward, but analcime content increases upward. Quartz content shows a slight decrease upward. Amounts of other minerals appear to be about the same in the upper and lower halves of the sequence.

LATERAL VARIATION IN COMPOSITION

Lateral variation in the composition of the dawsonite-rich zone on lower Piceance Creek was examined in a study of six suites of samples from localities within 1.5 miles north of the cut made by the U.S. Bureau of Mines (fig. 3). The mineral composition of these samples is listed in table 10. The tuff of unit 49 in the lower Piceance Creek section, referred to in this part of the report as tuff 13, provided a datum for correlation. Tuff 13 is exposed almost continuously north of station 3, as reported in

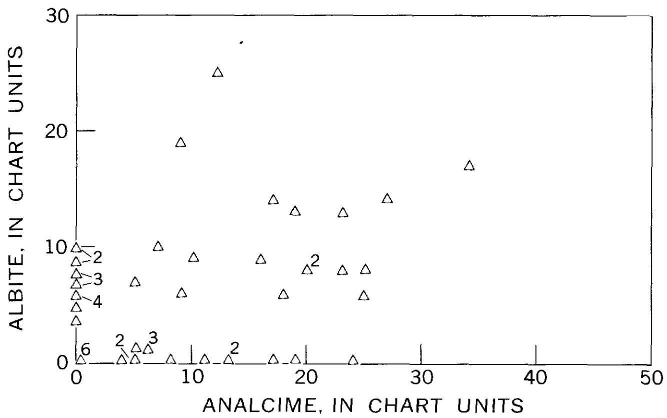


FIGURE 20.—Abundance of albite as a function of abundance of analcime in samples containing dawsonite, Parachute Creek Member. Numbers next to symbols indicate number of samples plotted at that position.

table 10. Data in table 10 indicate that the dawsonite-rich zone is at least 20 feet thick at the Bureau of Mines cut, where the base of the zone is not exposed, and is at least 40 feet thick at stations 2 and

TABLE 10.—*Mineral composition, expressed by X-ray peak height in chart units, of the dawsonitic oil-shale zone at six localities along lower Piceance Creek*

[Station localities are shown in fig. 3. D, dark brown; M, medium brown; L, light brown; USBM, U.S Bureau of Mines. Leaders (--), not detected]

Distance above or below tuff 13[1] (feet)	Dawsonite	Analcime	Quartz	Potassium feldspar	Albite	Dolomite	Calcite	Illite	Pyrite	Remarks
At USBM cut on lower Piceance Creek										
60.1	--	35	12	--	--	54	--	5	--	Marlstone (L); above the cut.
57.1	--	12	18	10	--	62	--	6	--	Marlstone, gray.
47.8	14	--	20	19	--	46	--	4	--	Oil shale (D).
40.8	--	28		5	--	68	--	9	--	Marlstone.
39.8	--	31	14	5	--	69	--	9	--	Marlstone, gray.
38.0	19	19	19	12	--	36	--	5	--	Oil shale, pebbly, blue-weathering.
37.0	--	13	33	45	64	--	--	--	--	Tuff.
36.0	--	21	14	6	9	76	--	5	--	Oil shale, pebbly, blue-weathering.
34.9	28	27	23	11	14	40	--	7	6	Oil shale (D).
23.4	--	17	11	6	7	74	--	8	--	Do,
22.4	--	80	40	10	8	--	--	--	--	Tuff 16.
12.0	--	1	7	--	73	--	--	--	--	Tuff 14.
10.5	--	20	18	10	13	77	--	6	--	Oil shale (D).
9.0	--	33	21	11	18	42	--	8	--	Do.
8.0	12	20	22	13	8	85	--	8	--	Do.
7.0	12	25	25	10	8	39	--	10	--	Do.
6.0	70	--	35	16	8	12	--	9	--	Do.
5.0	63	--	28	9	6	29	--	7	4	Do.
4.0	70	--	38	13	9	13	--	7	5	Do.
4.0	74	--	40	12	7	17	--	9	6	Do.
0	--	16	48	1	43	--	--	--	--	Tuff 13;[1] top of cut.
4.8	33	42	33	16	18	43	--	10	--	Oil shale (D).
5.8	30	24	28	23	--	47	--	7	4	Do.
6.8	89+	--	37	22	9	15	15	9	7	Do.
7.8	--	15	41	53	43	--	--	3	--	Do.
8.5	37	13	23	14	--	62	15	5	--	Do.
9.8	55	--	34	24	--	22	17	6	--	Oil shale (D); base of cut.
Station 1 (200 ft north of USBM cut)										
0	--	56	81	--	44	13		2	--	Tuff 13.[1]
2	25	34	24	9	17	77	--	9	--	Oil shale (M),
4.8	51	17	33	20	--	54	--	5	--	Oil shale (D).
5.8	70	--	34	19	10	14	15	8	--	Do.
6.5	52	--	29	12	10	60	--	6	--	Do.
6.8	14	13	13	7	7	82	--	3	--	Do.
Station 2 (700 ft north of USBM cut)										
33.1	20	17	21	15	14	36	--	6	4	Oil shale (D), blue-weathering.
33.0	20	35	18	30	84	--	--	2	--	Tuff 18.
26.0	--	33	16	6	6	56	--	6	--	Oil shale (M).
23.1	--	90	29	8	12	47	--	--	--	Marlstone, tuffaceous.
23.0	--	87	14	16	42	52	1	1	--	Tuff 17.
19.0	--	20	16	8	8	55	--	7	--	Oil shale (M).
13.5	32	11	18	6	--	52	--	6	--	Oil shale (D).
6.5	--	26	14	9	11	45	--	8	--	Do.
5.0	6	15	16	7	6	63	--	7	--	Do.
4.0	26	18	22	9	6	14	--	11	3	Do.
2.0	41	--	29	10	6	21	7	6	--	Do.
1.0	90	--	39	9	7	18	--	8	--	Do.
.3	73	--	33	11	9	10	--	7	1	Oil shale (D), papery.
0	--	8	33	20	49	2	--	--	--	Tuff 13.[1]
2.0	10	20	17	16	8	53	--	3	--	Oil shale (D).
4.8	35	9	31	9	6	28	--	5	--	Do.
5.8	48	--	24	12	5	11	8	4	--	Do.
6.8	72	--	29	14	8	6	--	4	--	Oil shale (M).
8.5	36	--	25	11	6	18	8	5	--	Do.
10.0	58	--	27	8	6	16	--	3	--	Oil shale (D).
16.0	25	19	18	8	13	33	--	4	4	Oil shale (D), blue-weathering.
18.5	14	23	16	7	13	45	1	5	--	Do.
21.0	25	7	21	13	10	30	--	4	2	Do.
21.6	--	12	25	8	8	34	8	7	--	Marlstone, sandy.
21.9	11	16	30	8	9	35	12	10	--	Do.
27.0	4	12	8	10	25	--	--	--	--	Tuff, dark.
Station 3 (2,200 ft north of USBM cut) [See units 40-70 in table 5 for description]										
Station 4 (about 1 mile north of USBM cut)										
0.0	45	54	44	11	20	--	--	--	--	Tuff 13.[1]
2.0	10	5	21	7	7	53	--	8	--	Oil shale (M).
4.8	--	--	5	6	--	90	--	--	--	Oil shale (D).
5.8	9	--	16	6	--	39	8	9	--	Do.
8.5	3	4	12	8	--	54	4	8	--	Oil shale (M).
10.0	--	8	15	4	5	62	4	10	--	Dolomite, green.
12.5	--	27	15	6	--	37	4	12	--	Oil shale (D).

TABLE 10.—*Mineral composition, expressed by X-ray peak height in chart units, of the dawsonitic oil-shale zone at six localities along lower Piceance Creek*—Continued

Distance above or below tuff 13[1] (feet)	Dawsonite	Analcime	Quartz	Potassium feldspar	Albite	Dolomite	Calcite	Illite	Pyrite	Remarks
Station 5 (1.5 miles north of USBM cut)										
0.0	-	19	35	32	--	11	--	-	-	Tuff 13.[1]
2.0	-	--	19	11	-	59	4	7	-	Oil shale (M).
4.8	-	--	14	9	--	14	20	14	-	Oil shale (L).
5.8	-	--	16	9	-	33	21	11	-	Do.
6.6	-	5	16	11	-	11	10	12	-	Oil shale (M).
8.5	-	13	11	4	4	55	7	8	-	Do.
10.0	-	4	19	8	9	36	4	12	-	Dolomite, green.
12.0	-	--	12	4	4	51	3	10	-	Oil shale (M).
12.5	-	5	12	7	4	31	6	15	-	Do.

[1]Tuff 13 is datum for these stations and is correlated with tuff 49 in the lower Piceance Creek section.

3. North of station 3, the oil shales are not as well exposed as farther south, but the dawsonite zone seems to have thinned to less than 10 feet at station 4 and is absent at station 5. Northward thinning of the dawsonite zone may be the result of deposition in a more shoreward environment that was not conducive to the formation of dawsonite or to the accumulation of material that later could cause its formation. In any case, the occurrence of dawsonite seems to cut across time-stratigraphic units.

TUFF BEDS

Major constituents of nearly all the exposed tuffs are analcime, quartz, potassium feldspar, and albite. Less abundant constituents are dolomite, calcite, micaceous minerals (including illite), and chloritic clay. The mineral composition of 74 tuff beds sampled in this study is shown in tables 4, 5, and 6 and is summarized in table 11.

Nearly all the samples contain analcime, and all of them contain quartz. Analcime content increases slightly westward from Rio Blanco to the pipeline section; it also tends to increase upward in both the lower Piceance Creek and the pipeline sections. Quartz content does not vary greatly but seems to increase slightly upward in the three sections. Potassium feldspar occurs in 66 of the 74 samples and shows a slight decrease upward in both the lower Piceance Creek and pipeline sections. Applying the X-ray methods of Wright (1968), we determined that the structural state of the potassium feldspar ranges between maximum microcline and high sanidine, but much is low sanidine. Albite also occurs in 66 of the 74 samples, and a few more samples from beds above the Mahogany marker have albite than from below the Mahogany marker. Again by applying the methods of Wright (1968), we determined that most of the sodium feldspar is albite in a low structural state—that is, albite of low-temperature origin—which suggests that it has been diagenetically altered in the sedimentary environment.

Less than half the tuffs contain dolomite, and only about one-third contain calcite. As in the marlstone and oil shale, calcite occurs in a broader range and commonly has higher values in the tuffs above the Mahogany marker than below it. Only about half the samples contain micaceous minerals. Dawsonite was detected in the tuffs of units 94, 52, and 34 in the lower Piceance Creek section and in tuffs 13 and 18 (of table 10) in some other outcrops along lower Piceance Creek.

SANDSTONE DIKES

Three gray to light brown sandstone dikes (units 150, 127, and 47) are exposed in the Rio Blanco section. The dikes are about 4 inches to 1 foot thick, and they fill irregularly but steeply dipping fractures in the oil shale and marlstone sequence. The sandstone is fine grained and consists of analcime, albite, quartz, some potassium feldspar, and traces of dolomite and calcite, suggesting that the original material was tuffaceous. The sharp contacts of the dikes with their enclosing rocks suggest that the sand filled fractures in already consolidated sediments. The tops and bottoms of the dikes are not exposed. Whether the dikes were formed by filling from the top down or by squeezing from the bottom up could not be determined.

CAVITIES

Many cavities were found in the rocks below the Mahogany ledge in each of the three measured sections of the Parachute Creek Member. The cavities range from a few inches to several feet across the largest dimension. They presumably once were filled with saline minerals, probably mostly nahcolite.

Many other details of structural features in the rocks of the Green River Formation were reported by Bradley (1929, 1931, 1964).

TABLE 11.—*Mineral composition, expressed by X-ray peak height*

[A, samples above Mahogany marker;

Stratigraphic position and number of samples	Analcime			Quartz			Potassium feldspar		
	Number of samples	Range	Arithmetic average	Number of samples	Range	Arithmetic average	Number of samples	Range	Arithmetic average
Pipeline section:									
A (7)	7	59-86	77	7	16-51	34	7	7-43	17
B (17)	15	0-86	60	17	5-56	24	15	0-65	23
Total (24)	22	0-86	62	24	5-56	27	22	0-65	21
Lower Piceance Creek section:									
A (9)	9	12-94	75	9	4-73	34	7	0-34	14
B (18)	18	5-96	52	18	5-90	32	17	0-41	18
Total (27)	27	5-96	60	27	4-90	33	24	0-41	17
Rio Blanco section:									
A (17)	16	0-88	56	17	17-80	34	16	0-35	14
B (6)	6	12-89	63	6	4-45	24	4	0-18	10
Total (23)	22	0-89	58	23	4-80	31	20	0-35	13
Summary:									
A (33)	32	0-94	65	33	4-80	34	30	0-43	14
B (41)	39	0-96	55	41	4-90	28	36	0-65	20
Total (74)	71	0-96	60	74	4-90	30	66	0-65	17

SEDIMENTATION AND DIAGENESIS

Sufficient information has been published to establish that in Eocene time the Piceance Creek basin contained a large lake of fresh to alkaline-saline water that was receiving detrital sediments from the surrounding higher regions. Much of this detrital sediment probably came from as much as 10,000 feet of sedimentary rocks of Cretaceous age which covered the region (Haun and Weimer, 1960). Many falls of volcanic ash of Tertiary age also contributed detrital sediment to the lake; this sediment chemically charged the river and lake waters with leached metals and silica and created a highly alkaline environment.

Vertical and lateral variations in composition of the rocks in the lower members of the Green River Formation in the Piceance Creek basin reflect differences in provenance of the materials delivered to the fresh-water lake in the basin during pre-Parachute Creek Green River time. By Parachute Creek time, the environment of deposition in the lake had changed from fresh to alkaline, and the bottom sediments were especially rich in carbonate and organic matter. In the late stages of deposition, during Evacuation Creek time, the water freshened again, and the sediments became more varied, although sand and volcanic materials were most abundant.

The great body of laminated carbonate rocks, some rich in organic matter, that comprise the Parachute Creek Member is most likely the product of sedimentation and diagenesis in the environment of an alkaline lake. Field relations described in this report suggest that the chemical composition of the lake water changed from time to time, indicating a lack of permanency of chemical stratification. Alkalinity of the bottom waters was probably greater than pH 9 most of the time. This alkaline water was overlain intermittently by fresher water. Between these two layers, as postulated by Bradley and Eugster (1969, p. B23), a zone of mixing of alkaline and fresh water undoubtedly existed at times; this zone allowed for the widespread distribution of calcium, magnesium, and bicarbonate ions and provided water fresh enough to have supported the algal life required to form the oil shale.

Large amounts of clay probably were delivered to the Piceance Creek basin during Parachute Creek time, but only small amounts of illite are detected now. Clays of different kinds that were swept into the alkaline lake yielded their constituents to form new minerals, including feldspar, quartz, analcime, and saline minerals. Whether the illite itself is detrital or is an alteration product is not known.

According to Alderman and Skinner (1957) and Alderman and von der Borch (1961), dolomite can precipitate from warm, strong brine. Dolomite commonly forms diagenetically from preexisting calcium-rich carbonate by the incorporation of magnesium during recrystallization, but the extremely fine grain of the dolomite in the rocks of the Parachute Creek Member strongly suggests that the dolomite is not a product of the recrystallization of preexisting calcium carbonate. More likely, much of the dolomite is a primary precipitate from the alkaline lake water.

Calcite in the rocks of the Parachute Creek Member also formed by precipitation from the lake water, but *in chart units, of 74 tuffs above and below the Mahogany marker*

B, samples below Mahogany marker]

Albite			Dolomite		Calcite		Illite		Chlorite	
Number of samples	Range	Arith-metic average	Number of samples	Range	Number of samples	Range	Number of samples	Range	Number of samples	Range
6	0-60	21	3	0-51	5	0-44	4	0-8	4	0-9
15	0-70	26	4	0-74	1	0-14	5	0-7	4	0-8
21	0-70	24	7	0-74	6	0-44	9	0-8	8	0-9
9	5-83	27	2	0-43	4	0-73	2	0-22	0	0
13	0-65	12	5	0-65	5	0-30	8	0-19	0	0
22	0-83	17	7	0-65	9	0-73	10	0-22	0	0
17	3-39	18	11	0-87	7	0-25	13	0-17	5	0-9
6	6-77	36	4	0-84	1	0-4	4	0-39	0	0
23	3-77	23	15	0-87	8	0-25	17	0-39	5	0-9
32	0-83	20	16	0-87	16	0-73	19	0-22	9	0-9
34	0-77	21	13	0-84	7	0-30	17	0-39	4	0-8
66	0-83	21	29	0-87	23	0-73	36	0-39	13	0-9

the water was probably fresher and lower in magnesium than that giving rise to the dolomite.

The sample data in tables 4, 5, and 6 from the three measured sections indicate that dolomite predominates greatly over calcite in rocks below the Mahogany ledge, but that, above the Mahogany ledge, calcite is more abundant and in some beds predominates over dolomite.

The bicarbonate chemical equilibrium system evidently hung in delicate balance but shifted frequently because of changes in such interrelated factors as climate, biological activity, and sedimentation. Interaction of these factors, causing turnover and mixing of the water, as well as alteration of conditions of the trophic levels of life and sedimentation, resulted in the accumulation of the thick sequence of laminated rocks of great lateral extent and uniform composition in the Parachute Creek Member. The changing chemical environments in the lake promoted diagenetic alteration of the organic and inorganic fractions of the sediment.

Decay of organic materials—mostly algae and pollen remains, according to Bradley (1970, p. 986-987)—produced carbon dioxide in the chemical system. The decay, however, was not complete, as indicated by the high carbon to hydrogen ratios in the oil shales (Smith, 1969, p. 186). Bacterial inhibitors, such as lauric acid, have been reported (Bradley, 1970, p. 995; Miller, 1972, p. B10) from Florida in modern sediments rich in organic matter. The presence of such bacterial inhibitors in a sediment would retard the oxidation of the enclosed organic matter. If a bacterial inhibitor had been present in the Piceance Creek basin, the dead algae accumulating on the bottom of the lake could have been preserved after partial decay, despite the alkaline (oxidizing) conditions prevailing there. This is not the only means of preserving organic matter. The organic matter literally could have been pickled at the chemocline interface (Rolfe and Brett, 1969, p. 229). Whatever the mechanism of preservation, the organic materials were involved in the diagenetic processes active in the basin. These processes likely resulted in the formation of various organometallic complexes, by extraction of metals from the brine, and polymers which evidently increased the stability of the organic matter in the environment and reduced its solubility in common organic solvents.

Quartz in these rocks probably has a mixed origin. Some is detrital, from both preexisting rocks and falls of volcanic ash, and some formed diagenetically from the breakdown of other minerals, such as analcime and, especially, the clay minerals.

The presence of sanidine, orthoclase, and microcline suggests that the potassium feldspars are of mixed origin—volcanic, detrital, and diagenetic. Orthoclase and microcline, neither of which is especially common, are probably of detrital origin. Sanidine is most likely of volcanic origin. Some potassium feldspar may have formed diagenetically, especially in the deeper parts of the basin. Authigenic development of such feldspars would have required extraction of potassium from the lake waters.

Plagioclases of different origins and compositions were probably originally deposited in the basin, but most of them are now albitic. Most of the albite studied in detail from both carbonate-rich rocks and tuff beds was determined by the methods of Wright

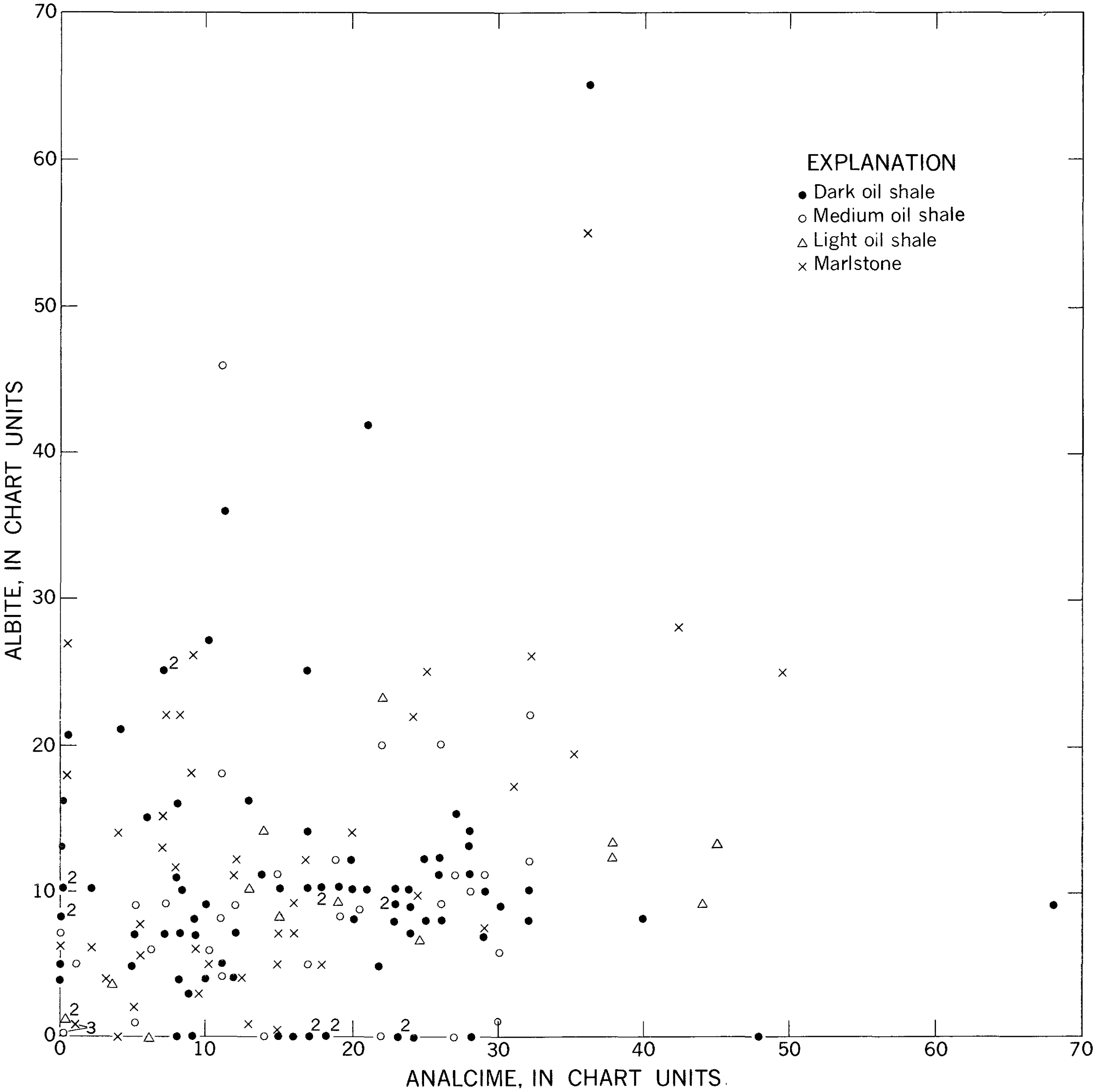


FIGURE 21.—Abundance of albite as a function of abundance of analcime in oil shale and marlstone, Parachute Creek Member. Numbers next to symbols indicate number of samples plotted at that position.

(1968) to be in the low structural state, in which the silicon and aluminum atoms are well ordered in the framework structure. This state is characteristic of a low temperature of formation and, therefore, a low energy level. The uniform composition of the plagioclase suggests that plagioclases of varied compositions and structural states that probably were originally deposited in the lake from various sources were altered diagenetically in the alkaline environment to a more sodium-rich albite in a lower structural state.

Analcime, which is a common, widespread authigenic mineral in the exposed carbonate rocks and tuffs of the Parachute Creek Member in the Piceance Creek basin, formed at low temperatures in moderately alkaline water from clays and zeolitic precursors, themselves derived from volcanic glass. Conditions fostering the formation of analcime from other zeolitic minerals or the conversion of analcime to feldspar in environments of higher alkalinity were discussed by Hay (1966) and Sheppard and Gude (1968, 1969), among others.

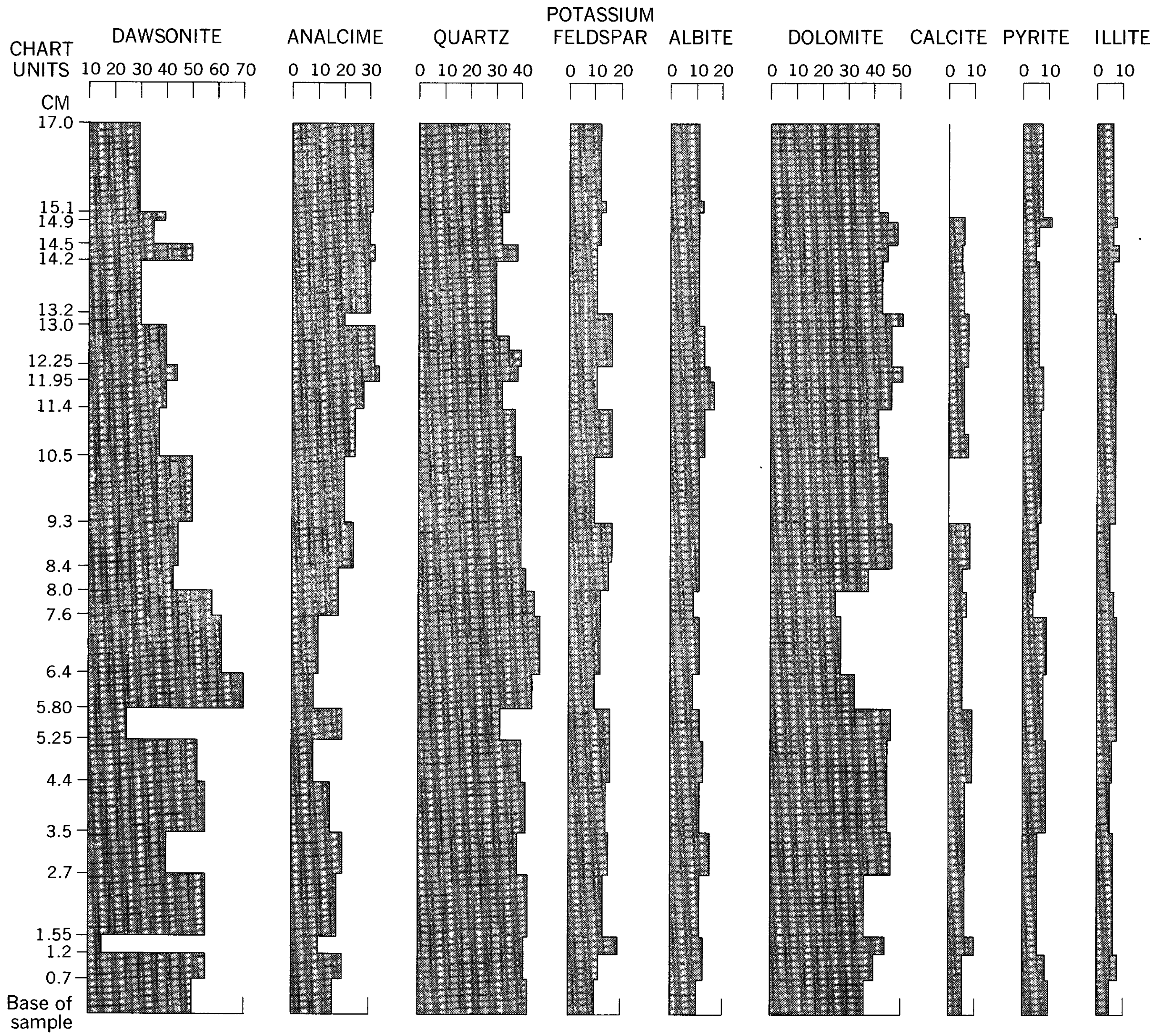


FIGURE 22.—Mineral composition of dawsonitic, pyritic oil shale along lower Piceance Creek road, as expressed by X-ray peak height in chart units.

Zeolitic precursors of analcime have not been found in the Piceance Creek basin, but their absence may be partly explained by the erosion of shoreward deposits around all but the southernmost periphery of the basin. Presumably the alkalinity of the water in which the preserved beds were saturated was sufficiently high to convert all earlier zeolites to analcime. The data in figure 19 show that analcime in 40 of 56 tuffs that lack dawsonite has a composition (34.5-35.1 atoms of silicon per unit cell) similar to that of analcime derived from clinoptilolite in tuffs of the Barstow Formation of California described by Sheppard and Gude (1969, p. 29). The close comparison lends weight to the argument that at least some of the analcime was derived from clinoptilolite. Where the alkalinity increased further (pH>9), some analcime reacted to form dawsonite and quartz. Rocks containing both analcime and dawsonite are exposed along lower Piceance Creek. Deeper in the interior of the basin, all the analcime has been converted under highly alkaline conditions to dawsonite and quartz or to albite.

Most of the saline minerals are soluble under conditions of weathering and have been removed from rocks in the outcrops, except for the dawsonite, which is tightly enclosed in rocks on lower Piceance Creek. The presence of many zones of cavities in the three measured sections suggests that some saline minerals were deposited in pods and disseminated crystals near the edges of the basin. Scattered pods and crystals of nahcolite, dawsonite, and other saline minerals probably formed diagenetically from materials in the lake sediment that reacted with trapped brine during burial.

In the lower part of the Parachute Creek Member in the deeper parts of the basin are beds of nahcolite, which contain some dawsonite, and some stratigraphically higher beds of halite, which contain thin interlayers of nahcolite and accessory amounts of wegscheiderite ($Na_2CO_3 \cdot 3NaHCO_3$), shortite ($Na_2CO_3 \cdot 2CaCO_3$), northrupite ($Na_2CO_3 \cdot MgCO_3 \cdot NaCl$), searlesite ($NaBSi_2O_6 \cdot H_2O$), and possibly trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) (Hite and Dyni, 1967). Nahcolite in the Piceance Creek basin probably precipitated from brines in much the same manner as did trona in the Green River basin. Nahcolite is the major saline mineral in the Piceance Creek basin, however, because the partial pressure of carbon dioxide at the critical temperature of the lake precluded precipitation of trona (Bradley and Eugster, 1969, fig. 2 and p. B46-B58). The beds of halite in the Piceance Creek basin also probably precipitated from brine, very likely by brine mixing in the manner described by Raup (1970). Bradley and Eugster (1969, p. B22-B24) discussed the evidence for brine mixing rather than evaporation to account for the origin of halite and saline minerals in the Green River basin. The same reasoning can be applied to the Piceance Creek basin.

The possibility that the dawsonite in the nahcolite beds in the deeper part of the basin is a primary precipitate from alkaline water should not be overlooked. Aluminum ions in preexisting aluminosilicate gels and in minerals that were attacked by highly alkaline lake water could have been available to form dawsonite by direct precipitation from the water at the same time as the nahcolite.

The formation of dawsonite by diagenesis and by primary precipitation from alkaline lake waters and the occurrence of dawsonite at the periphery of the basin as well as at depth in the central part suggest that greater amounts of dawsonite occur in this basin than have previously been recognized. The amount of aluminum potentially available in the dawsonite of the Piceance Creek basin may be one of this nation's great resources of an industrially valuable commodity.

Sulfate minerals did not survive in the lake. According to Jones (1966, p. 196), sulfate is decreased in the permanent lacustrine environment by bacterial reduction. Sulfur from the sulfate ion becomes fixed as pyrite or is lost to the air as hydrogen sulfide rising from mudflats at the lake margins. Sulfate minerals found in samples from outcrops are oxidation products formed by weathering of the rocks.

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