Geology of Southwestern North Park and Vicinity Colorado

GEOLOGICAL SURVEY BULLETIN 1257

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By WILLIAM J. HAIL, Jr.

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A study of the areal geology of parts of the North and Middle Park basins, Jackson and Grand Counties, Colorado

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CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

GEOLOGY OF SOUTHWESTERN NORTH PARK AND VICINITY, COLORADO

By William J. Hail, Jr.

ABSTRACT

The area of this report occupies 340 square miles in southwestern North Park and northwestern Middle Park, Jackson and Grand Counties, Colo. North and Middle Parks are topographic basins and together form a single structural basin. The mapped area lies along the east flank of the north-trending Park Range and includes the west end of the west-trending Rabbit Ears Range. The Continental Divide roughly follows the crestline of the Rabbit Ears Range and separates Atlantic Ocean drainage north of the range from Pacific Ocean drainage to the south. Elevations range from 7,670 feet at Muddy Creek in the south to just above 11,000 feet along the crest of the Rabbit Ears Range in the east. The topography consists of lowlands in the northeast and south and low mountainous or hilly ground elsewhere. The climate is cool and semiarid to moderately moist. Stock raising and timber cutting are the principal industries.

Precambrian crystalline rocks include an older unit of quartz monzonite gneiss and a younger intrusive unit of quartz monzonite. The gneiss underlies only a small area in the northwest where it consists of a fine-grained layered to massive pink or red to yellowish-gray rock cut by sparse pegmatite. The intrusive quartz monzonite comprises most of the Precambrian rocks and is a pink, red, or orange coarse-grained rock that consists of quartz (29 percent), plagioclase (30 percent), alkalic feldspar (34 percent), biotite (5 percent), and minor accessory minerals.

The sedimentary rock sequence ranges in age from Permian to Quaternary. The maximum thickness of pre-Quaternary sedimentary rocks is about 16,000 feet.

The oldest formation is the Chugwater Formation of Permian and Triassic age and consists of interbedded red siltstone, sandstone, and shale.

The Sundance Formation of Late Jurassic age ranges in thickness from 93 to 224 feet, and unconformably overlies the Chugwater. It consists of a lower member of fine-grained light-gray to pink sandstone, and an upper member of calcareous marine shale and siltstone, and locally of glauconitic sandstone.

The Morrison Formation of Late Jurassic age conformably overlies the Sundance, and ranges in thickness from 340 to 500 feet. In the lower part it consists mostly of nonmarine varicolored claystone and gray to brown calcareous sandstone and in the upper part mostly of gray to green claystone.

The Dakota Sandstone of Early Cretaceous age overlies, in part unconformably, the Morrison Formation. It ranges in thickness from about 100 to 200 feet. The lower of its two members consists of nonmarine siltstone, claystone, sandstone, and conglomerate. The upper member consists of gray to black claystone

and shale, gray to brown sandstone, and siltstone. The Dakota generally forms a resistant hogback.

Conformably overlying the Dakota is the Benton Shale of Early and Late Cretaceous age. It ranges in thickness from 420 to about 500 feet. The Benton includes three members: the Mowry Shale Member at the base, consisting of light-gray-weathering silty shale and minor bentonite beds; the middle shaly member, consisting of nonresistant dark-brownish-gray calcareous to noncalcareous shale, sparse bentonite beds, and bluish-black ironstone concretions; and the Codell Sandstone Member, consisting of calcareous sandstone, calcarenite limestone, shale, and siltstone. The three members were mapped as one unit.

Overlying the Benton with possible disconformity is the Niobrara Formation of Late Cretaceous age. It ranges in thickness from about 700 to 800 feet. It includes the thin basal Fort Hays Limestone Member, which consists of granular gray limestone and some dark-gray calcareous shale and shaly limestone, and the Smoky Hill Shale Member, which consists of dark-gray yellow to light-gray-weathering calcareous shale and shaly limestone.

The Pierre Shale of Late Cretaceous age conformably overlies the Niobrara and has a thickness of as much as 5,000 feet. It is divided into two map units: the shaly member and the overlying sandy member. The shaly member, as much as 2,400 feet thick, consists mostly of dark-gray marine shale. The sandy member, as much as 3,000 feet thick, consists of marine sandstone, shale, sandy shale, and siltstone.

A major unconformity separates the Pierre Shale and older formations from younger rocks. The oldest Tertiary formation is the Coalmont Formation of Paleocene and Eocene age. It reaches a possible aggregate maximum thickness of 12,000 feet and is locally divided into three members: the Middle Park Member at the base, the middle member, and the upper member. The Middle Park Member consists of arkosic sandstone and conglomeratic beds, volcanic pebble conglomerate, and sandy claystone or mudstone. The middle member is similar in lithology to the Middle Park Member but lacks volcanic pebble conglomeratic beds and contains some carbonaceous shale. The upper member consists mostly of arkosic sandstone, claystone or mudstone, carbonaceous shale, and some lenticular coal beds. Two small outcrops of limestone, ashy sandstone, or siltstone are assigned to the North Park Formation of late Miocene age.

Tertiary igneous rocks range in age from Oligocene to Miocene and possible Pliocene. Extrusive rocks comprise the Rabbit Ears Volcanics and younger extrusive rocks and consist mostly of pyroclastic breccia, volcanic ash, and some intercalated flows of rhyodacite, latite, trachyandesite, and trachybasalt. Intrusive igeous bodies are mapped separately and include rhyolite, quartz latite, rhyodacite, trachyte, latite, trachyandesite, trachybasalt, and basanite. These occur as dikes, sills, plugs, possibly laccoliths, and flows.

Pleistocene deposits include till of three glaciations, outwash terrace gravels (in part glaciofluvial in origin), pediment gravels, and block slides. Deposits of Pleistocene and Recent age undifferentiated include landslides and colluvium. Recent deposits include valley-flat alluvium.

The mapped area occupies part of the west flank of the North Park-Middle Park structural basin. Simple anticlinal uplift without faulting marks the basin margin in all but the northwesternmost part of the area. Several northwest-striking normal faults of less than 500 feet stratigraphic displacement cut the Coalmont in the northeastern part of the area, and several small anticlines and synclines parallel the faults. Other normal faults cut the Coalmont elsewhere in the area. A major pre-Coalmont structure is indicated near the east-central boundary of the area at Arapaho Creek, where Cretaceous rocks are exposed. Several faults of small displacement near Muddy Pass cut the Niobrara and Benton Formations. A faulted anticline dominates the structure in the south-central part of the area, and a small faulted syncline adjoins this faulted anticline near Whiteley Peak. A northeast-striking compound anticlinal structure enters the area at its south boundary.

Pre-Laramide Mesozoic tectonic activity was not great, as indicated by the lack of major angular unconformities. Laramide tectonism began in latest Cretaceous or early Tertiary time with uplift of the bordering Park Range, which was accompanied by folding, faulting, and erosion of the pre-Tertiary rocks. The Coalmont Formation locally overlaps the entire pre-Coalmont sedimentary sequence. One or more local unconformities within the Coalmont indicate continued tectonism in early Tertiary time. Post-Coalmont folding and faulting accompanied and probably followed episodes of volcanic activity beginning in the Oligocene and ending in late Miocene or early Pliocene. Basin deepening and marginal uplift apparently continued at least through the Pleistocene.

No minerals are mined in the area at the present time, although coal production from the Coalmont Formation has been large in the past. Large amounts of gravel are used locally for road surfacing. Small amounts of manganese have been produced from trachybasalt rubble in surficial material near Rabbit Ears Pass. Much prospecting for oil and gas, uranium, fluorspar, gold, and, reportedly, rare earths has been done.

INTRODUCTION

Location.—The mapped area occupies 340 square miles mostly in southwestern North Park, Jackson County, and partly in the northwest corner of Middle Park, Grand County, Colo. Both North and Middle Parks are broad intermontane topographic basins. The area lies adjacent to the east flank of the north-trending Park Range, and includes the west end of the east-trending Rabbit Ears Range. The area comprises the Teal Lake, Coalmont, Rabbit Ears Peak, Spicer Peak, Lake Agnes, and Whiteley Peak 7½-minute quadrangles. The geologic map is divided into three sheets, plates 1–3. (See index map, fig. 1.)

This report is the second of a series on the North Park basin, Colorado. The first report (Hail, 1965) is on northwestern North Park. D. M. Kinney is examining the geology of eastern North Park.

Previous work.—The earliest geologic work in this area was mostly rapid reconnaissance conducted by geologists of the King and Hayden Surveys in the late 1860's and 1870's. Notable in this work was the survey of Middle Park by Marvine (1874), whose report touched on part of the area here included in the Lake Agnes and Whiteley Peak quadrangles. Grout, Worcester, and Henderson (1913) described a reconnaissance of the Rabbit Ears Peak area and included a geologic map at a scale of 1:63,360. Beekly (1915), of the U.S. Geological Survey,

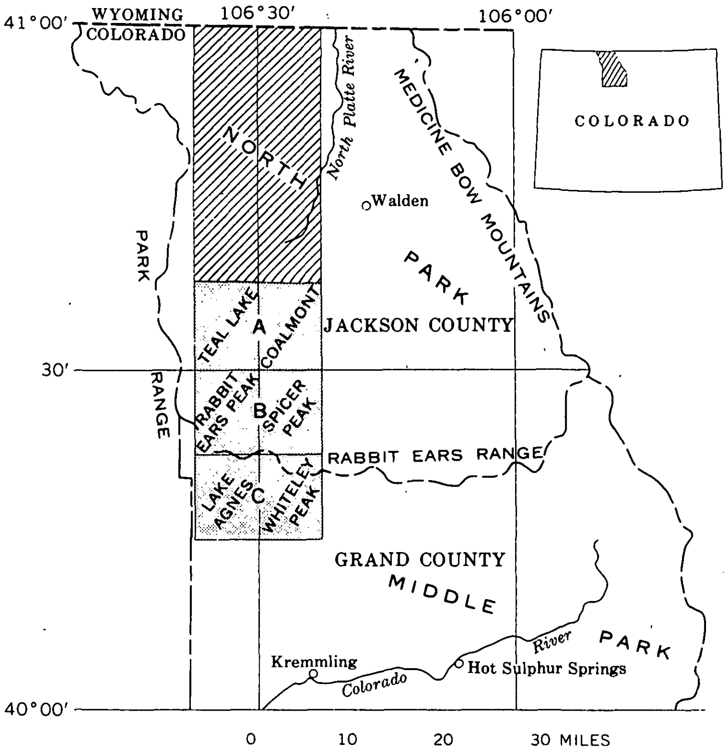

FIGURE 1.—Index map showing location of report area (stippled). Area A refers to plate 1; B, plate 2; and C, plate 3. Area shown by diagonal line pattern mapped in Hail (1965, pls. 1–3).

made a reconnaissance study of North Park and included a geologic map at a scale of 1:125,000. Erdmann (1941), also of the U.S. Geological Survey, described the coal deposits of the Coalmont area, and Atwood (1937) described the main glacial features of the Medicine Bow and Park Ranges in the North Park area. A guidebook of the Rocky Mountain Association of Geologists (1957) contains papers on the geology of North and Middle Parks. At least two university theses (Marr, 1931; Scott, 1961) describe the geology of parts of the area.

Fieldwork.—The field investigations were made mostly during part of 1958 and during the summers of 1960–64. Lawrence D. Taylor assisted in mapping the Teal Lake quadrangle in 1958. Geologic mapping was done in part directly on field sheets and in part on aerial photographs and was later compiled by multiplex methods.

GEOGRAPHY

Topography.—The mapped area straddles part of the Continental Divide and includes areas of considerable relief, as well as nearly flat-lying areas on the floor of the North Park basin. Both the highest and the lowest points in the area lie in the Whiteley Peak quadrangle. The highest point, just above 11,000 feet, is on the crest of the Rabbit Ears Range about 1½ miles northeast of Red Slide Mountain; the lowest point, about 7,570 feet, is on Muddy Creek at the south boundary of the area.

Climate and vegetation.—Southwestern North Park has a cool semiarid to moderately moist climate. Climate records, kept at the Spicer station in the eastern part of the area for an 18-year period prior to 1952, show a mean January temperature of about 16°F, a mean July temperature of about 59°F, and an average annual precipitation of about 14 inches (U.S. Weather Bur., 1959, p. 36, 47). Mountainous areas have considerably more precipitation, although records are not available for them.

Vegetation in the lowland areas is mostly sagebrush and sparse grass; however, grass for hay and grazing grows abundantly in lowland irrigated areas and in valley flats. Low hills support thick stands of aspen and sparse stands of pine and spruce; the higher areas of the Park Range and the Rabbit Ears Range support a heavy growth of pine, spruce, and fir. None of the area is above timberline.

Industry.—Stock raising is the principal industry of the area. The timber potential is large, and tree cutting has been extensive in the past, particularly in the Rabbit Ears Pass-Muddy Pass area and in the Sawmill-Crosby Creeks area. Small timber operations were carried on in 1964 in the Arapaho Pass area (Spicer Peak quadrangle) and just southwest of Rabbit Ears Pass, outside the mapped area. A small sawmill is in operation on U.S. Highway 40, a mile southeast of Muddy Pass. Hunting, fishing, and camping attract many tourists. No minerals are mined at the present time (1965), although coal production at Coalmont has been large in the past. A small manganese operation near Rabbit Ears Pass is no longer active. No towns are in the area, and the village of Coalmont is now virtually abandoned.

Accessibility.—U.S. Highway 40 and Colorado Highway 14 join at Muddy Pass and give access to the area. Steamboat Springs is about 27 miles northwest of Muddy Pass, Kremmling 27 miles southeast, and Walden about 35 miles northeast. Numerous gravel county roads and dirt ranch roads give fair access to much of the area, but some of the mountainous and heavily forested areas can be reached only on foot or by horse.

CRYSTALLINE ROCKS—PRECAMBRIAN

The Precambrian rocks in the area were not studied in detail. They are similar to the Precambrian rocks to the north, along the Park Range flank, and are divided into two units: metamorphic rocks, consisting mostly of fine-grained quartz monzonite gneiss, and a younger unit of intrusive quartz monzonite. Hague (Hague and Emmons, 1877, p. 130–141) described the Precambrian rocks of the Park Range and classified them as granites, micaceous and hornblendic gneisses and schists, and syenites and diorites. Grout (in Grout and others, 1913, p. 43–44) described the Precambrian rocks along Muddy Creek as intrusive granite.

METAMORPHIC ROCKS

Metamorphic rocks are present only in a single small outcrop in the extreme northwest corner of the Teal Lake quadrangle. These rocks consist mostly of layered to massive fine-grained quartz monzonite gneiss but also include some interlayered and crosscutting pegmatite. The gneiss is pink or red to yellowish gray but becomes dark gray where it contains abundant biotite and weathers brownish red or yellowish gray. Foliation of the gneiss is made by parallel layers of biotite, which though not abundant, are conspicuous.

Three samples of gneiss were examined petrographically by Don L. Gustafson of the U.S. Geological Survey. According to Gustafson, the gneiss is composed of quartz, plagioclase, and potassium feldspar and of minor amounts of biotite. Other minerals, including magnetite, muscovite, sphene, garnet, chlorite, and apatite, are present in very minor amounts. The plagioclase is mostly oligoclase; the potassium feldspar is mostly microcline. Quartz content ranges from 36 to 39 percent, plagioclase content from 20 to 30 percent, potassium feldspar content from 20 to 35 percent, and biotite content from 4 to 9 percent. The quartz is anhedral, contains numerous dusty inclusions, and is flattened parallel to the foliation. The plagioclase is anhedral, and much of it is altered to sericite. The microcline is anhedral, and shows well-formed microperthitic structure. The biotite occurs in raggedly terminated flakes and shows strong dimensional orientation.

INTRUSIVE QUARTZ MONZONITE

Coarse-grained intrusive quartz monzonite crops out irregularly along the Park Range flank. Two small patches crop out in the Teal Lake quadrangle, one in the extreme northwest corner, the other near Little Grizzly Creek at the west-central boundary. The largest exposure of intrusive quartz monzonite crops out along the west boundary of the Lake Agnes quadrangle where it reaches a maximum width of about 1¼ miles. The high and rugged topography of the Park Range, formed on these and other Precambrian rocks, is exhibited only in the outcrop area in the northwest corner of the Teal Lake quadrangle, where precipitous cliffs bordering Beaver Creek are as much as 1,100 feet high.

Petrographic examination of 13 samples, taken in and near the mapped area, was made by Don L. Gustafson. Eleven of the 13 samples are quartz monzonite, and two are granodiorite. As here used, quartz monzonite includes rocks having quartz in excess of 10 percent, and plagioclase-potassium feldspar ratios between 2:1 and 1:2; granodiorite exceeds the 2:1 ratio.

The quartz monzonite consists chiefly of quartz, plagioclase, and potassium feldspar and subordinate biotite. Quartz ranges from 14 to 45 percent in the 11 samples and averages 29 percent. Plagioclase ranges from 25 to 38 percent and averages 30 percent. Potassium feldspar ranges from 20 to 42 percent and averages 34 percent. Biotite is present in nine of the 11 samples in amounts ranging from about 1 to 9 percent. The two samples of granodioritic composition contain 23 and 30 percent quartz, 49 and 46 percent plagioclase, 13 and 16 percent potassium feldspar, and 13 and 7 percent biotite. The potassium feldspar in the quartz monzonite and granodiorite is microcline; the plagioclase is oligoclase, much of which is altered to sericite, Minor accessory minerals include hornblende, magnetite, chlorite, muscovite, apatite, sphene, epidote, hematite, and leucoxene; they probably total less than 1 percent of the rock.

The quartz, potassium feldspar, and plagioclase occur mostly in subhedral to anhedral masses and form a typically granitic texture. Most of the quartz monzonite is coarse grained; locally, however, the rock is fine to medium grained. The larger crystals commonly range from ½ to 2 cm in length, but some crystals are as much as 6 cm in length.

In fresh outcrops the quartz monzonite is mostly pink, red, or orange and locally shades to gray. Colors of the weathered rock are shades of brown, mostly reddish or yellowish brown.

A dike of black hornblendite in the quartz monzonite crops out in the extreme southwest corner of the Lake Agnes quadrangle, but it was not mapped separately.

SEDIMENTARY ROCKS

The sedimentary rocks in southwestern North Park range in age from Permian to Quaternary. The geologic maps, plates 1–3, show the areal distribution of the units.

The oldest known sedimentary rocks in the area are Permian or Triassic: the mapped area lies in the region of the ancestral Rocky Mountains, and rocks older than Permian have been stripped away by erosion if they were ever present. The maximum aggregate thickness of the pre-Quaternary sedimentary rocks in southwestern North Park is about 16,000 feet. Table 1 shows a generalized section of pre-Quaternary sedimentary rocks.

The sedimentary rocks are mostly nonresistant and easily eroded. Sandstone and conglomerate beds of the Dakota Sandstone are generally resistant, however, and form a hogback. The sandstone and limestone of the thin Codell Sandstone Member of the Benton Shale also are resistant, and locally form a low ridge or hogback.

This report uses, with some modification, the geologic names used in four previous reports on North Park: Beekly (1915), Steven (1954, 1960), and Hail (1965).

TABLE 1.—*Generalized section of pre-Quaternary sedimentary rocks*

System or series	Formation and member		Thickness (feet)		Lithology
Miocene	North Park Formation		0–80		Light-gray ashy locally conglomeratic limestone; light-gray to tan fine-grained ashy sandstone, or siltstone, and volcanic ash.
	Unconformity				
Eocene	Coalmont Formation	Upper member	0–12,000?	200–5,500?	Brown carbonaceous shale in lower part, interbedded with gray to brown arkosic locally micaceous sandstone, claystone, mudstone, and carbonaceous shale. Local lenticular coal beds and sparse conglomeratic sandstone in upper part.
		Middle member		1,000–6,000?	Brown to gray arkosic sandstone, conglomerate, and conglomeratic sandstone, sandy claystone or mudstone, and locally, silty to micaceous carbonaceous shale and thin coal beds.
Paleocene		Middle Park Member		0–600	Brown to gray arkosic sandstone, conglomeratic sandstone, sandy claystone or mudstone, volcanic rock-pebble conglomerate, and sparse carbonaceous shale.
	Unconformity				
Upper Cretaceous	Pierre Shale	Sandy member	0–5,000	0–3,000	Interbedded brown to gray calcareous sandstone, siltstone, and shale; a minor amount of clay-pebble conglomerate and scattered calcareous concretionary masses.
		Shaly member		0–2,400	Gray shale, calcareous near base, becoming silty to sandy near top; contains thin rusty siltstone laminae and scattered locally calcareous claystone or siltstone masses.
	Niobrara Formation	Smoky Hill Shale Member	700–800	685–780	Dark-gray thin-bedded to fissile calcareous shale in lower part; interbedded dark-gray fissile calcareous shale and thin shaly limestone in upper part; weathers light gray to light yellow.
		Fort Hays Limestone Member		15–23	Gray to brownish-gray, finely granular limestone; weathers light gray.

TABLE 1.—*Generalized section of pre-Quaternary sedimentary rocks*—Continued

System or series	Formation	Member	Thickness (feet)	Member thickness (feet)	Lithology
Upper Cretaceous—Con.	Benton Shale	Codell Sandstone Member	420–500	30–60	Calcareous sandstone, calcarenite limestone, shale, and siltstone.
		Middle shaly Member		290–350	Black to dark-brownish-gray shale, noncalcareous in lower part to highly calcareous in upper part; thin bentonite beds mostly in lower part; conspicuous blue-black ironstone concretions in lower part.
		Mowry Shale Member		100–125	Dark-gray, silty thin-bedded to fissile platy shale; weathers light gray; contains abundant fish scales and minor thin bentonite beds.
Lower Cretaceous	Dakota Sandstone	Upper member	140–200	75–130	Lower part is light-gray to grayish-brown fine-grained locally carbonaceous sandstone and some dark-gray to black shale or claystone; middle part is light-gray to medium-brown fine- to medium-grained sandstone and locally thin shale; upper part is interbedded gray to light-brown siltstone and gray or black carbonaceous silty claystone.
		Lower member		17–116	Light-gray to brownish-gray sandstone, conglomerate, and conglomeratic sandstone; has minor gray to grayish-green, locally red, claystone and siltstone.
	—Unconformity—				
Upper Jurassic	Morrison Formation		340–500		Gray, green, and dark-red claystone; brown to gray calcareous sandstone, and minor calcareous siltstone, shale, and limestone.
	Sundance Formation	Upper member	93–224	44–60	Interbedded light-gray to light-yellowish-brown locally glauconitic calcareous sandstone, light-gray clayey siltstone, and gray to yellowish-gray shale.
		—Unconformity—			
		Lower member		63–166	Very light gray to orange-red or pink fine-grained nonresistant sandstone.
	—Unconformity—				
Triassic and Permian	Chugwater Formation		0–700		Interbedded fine-grained calcareous red sandstone, siltstone, and shale
	—Unconformity—				
Precambrian					Metamorphic rocks and intrusive quartz monzonite.

PERMIAN AND TRIASSIC SYSTEMS

CHUGWATER FORMATION

The Chugwater Formation includes the red-bed sequence between the Precambrian and the base of the Sundance Formation. The Chugwater is easily eroded and forms valleys or slopes.

The exact thickness of the Chugwater is not known, but it probably ranges from about 700 feet in the northern part of the area to zero in the southeast. Drill-hole information shows that the Chugwater pinches out and is absent about 7 miles east of the mapped area in the western part of T. 6 N., R. 79 W. An exposure of the Chugwater about a mile north of the north boundary of the area along the Park Range is about 700 feet thick. In the northeastern part of the area, the Hiawatha Government 1–25 test hole (SW¼ sec. 25, T. 7 N., R. 81 W.) penetrated 230 feet of Chugwater before entering granite. In the southeastern part of the area, the DeBerard State 1 test hole (SE¼ sec. 27, T. 4 N., R. 81 W.) was drilled to Precambrian apparently without penetrating any Chugwater. The Chugwater along Frantz Creek in the southwestern part of the area ranges from 90 to 150 feet in thickness. Thus, southeastward thinning of the Chugwater is indicated; thinning is due to depositional wedging against the Precambrian and to erosion. Nondeposition of its lower beds against the eroded slopes of the ancestral Rocky Mountains largely controlled the basal thinning. An unconformity separates the Chugwater from the overlying Sundance Formation.

The Chugwater consists of interbedded red siltstone, fine-grained sandstone, and shale. Locally the red beds are sparsely mottled light green or gray. The siltstone and sandstone are thin and even bedded. The sandstone and some of the siltstone beds are calcareous, and much of the shale and siltstone is micaceous. The fact that the contact of the Chugwater on the Precambrian is generally free of Precambrian detritus indicates that the Precambrian was a cleanly stripped surface probably of little relief. In places, soft shale rests on the Precambrian, only the lower half-foot or so containing sparse Precambrian detritus.

Fossils are absent from the Chugwater in this area, and the formation's age is not definitely known; it is designated Permian and Triassic. In northwestern North Park the Chugwater contains probable equivalents of the Forelle Limestone of Permian age near the base and of the Jelm Formation of Triassic age at the top. In southwestern North Park, however, neither Forelle nor Jelm equivalents can be recognized. In the northern part of the Gore Pass 15-minute quadrangle, probable equivalents of the Chinle Formation of Late Triassic age are present, unconformably overlying rocks lithologically similar to the Chugwater in the Lake Agnes quadrangle. In the Glenwood Springs quadrangle, 40 miles southwest of this area (Bass and Northrop, 1963, p. 46–54), the Maroon Formation immediately underlies the Chinle Formation. The upper part of the Maroon in that area is Permian in age and contains red beds similar to those of the Chugwater of southwestern North Park. In the Gore Pass area, about 12 miles south of the Lake Agnes quadrangle, F. G. Poole (oral commun., 1965) included red beds below the Chinle in the State Bridge Formation (Quigley, 1965, p. 1981), which, in the Gore Pass area, is designated as Permian in age. A Permian age is suggested for the thin

Chugwater at the south margin of the area of this report. As the Chugwater thickens near the north boundary of the area, it may contain beds of Triassic age.

JURASSIC SYSTEM

SUNDANCE FORMATION

The Sundance Formation of Late Jurassic age unconformably overlies the Chugwater Formation and conformably underlies the Morrison Formation. It consists of two members; a lower sandstone member and an upper member consisting of interbedded marine shale, siltstone, and sandstone. The formation is nonresistant and good exposures are rare. Sparse information from outcrop and drillhole indicates a range in thickness from 93 to 224 feet. Most of the variation in thickness is due to differences in thickness of the lower sandstone member.

Lower member.—The lower part of the Sundance ranges in thickness from 63 feet in the DeBerard test hole to 166 feet near Frantz Creek. The large range in thickness of this member is probably due to deposition on an irregular erosion surface. This member is a fine-grained well-sorted very light gray to light-orange-red or pink sandstone. At Frantz Creek the basal 2 feet is gritty. It is mostly friable and nonresistant but locally is resistant, presumably where cemented by lime. No bedding is apparent, and it lies with sharp unconformity on red beds of the Chugwater Formation.

Upper member.—The upper member of the Sundance ranges in thickness from about 44 feet in the Hiawatha test hole to at least 60 feet near Frantz Creek. It rests with a sharp, possibly unconformable, contact on the lower sandstone member. It consists of nonresistant interbedded marine sandstone, siltstone, and shale. Most of the unit is calcareous. The sandstones are light gray to light yellowish brown and locally glauconitic, and some beds contain fossil *Camptonectes* and *Ostrea* (identified by G. N. Pipiringos). The siltstones are light gray to yellowish gray and clayey; the shales are gray to yellowish gray.

The following partial stratigraphic section of the Sundance was measured just north of Barber Basin:

Partial section of the Sundance Formation in the NW¼ sec. 17, T. 4 N., R. 82 W.

[Measured by G. N. Pipiringos and W. J. Hall]

	Feet
Sundance Formation (part):	
Upper member (part):	
8. Sandstone, yellowish-gray, very fine grained, poorly sorted, silty, limy, glauconitic; contains a few resistant sandstone ledges similar to unit 7; higher beds covered	5

Partial section of the Sundance Formation in the NW¼ sec. 17, T. 4 N., R. 82 W.—Continued

	Feet
Sundance Formation (part)—Continued	
Upper member (part)—Continued	
7. Sandstone, light-gray, very fine grained; better sorted and cleaner than sandstone of unit 8; slightly limy, coquinal, consisting principally of *Camptonectes* and *Ostrea* shell fragments; forms resistant square-faced ledge	4
6. Siltstone, yellowish-gray, clayey	19
5. Shale, yellowish-gray; contains lenses of platy limy sandstone	3
4. Sandstone, yellowish-gray, very fine grained, clayey, silty	3
3. Shale, yellowish-gray, silty; grades into unit 2	16
2. Siltstone, yellowish-gray, clayey; grades into unit 3	2
Partial thickness upper member	52
Lower member (part):	
1. Sandstone, lower part predominantly orange pink with light-gray bands, upper part predominantly grayish white with pink bands; fine grained, well sorted, clean, friable; contains a few chert and quartzite grains; top few feet weathers yellow and contains bottom dweller burrow casts; base covered	60+
Partial thickness, Sundance Formation	112+

Beds 2 through 6 are probable equivalents of the Lak Member of the Sundance, and beds 7 and 8 are probable equivalents of the Pine Butte Member of the Sundance (Pipiringos, 1968).

The following partial stratigraphic section of the Sundance was measured near the head of Frantz Creek:

Partial section of the Sundance Formation in the SE¼ sec. 32, T. 4 N., R. 82 W.

[Measured by G. N. Pipiringos and W. J. Hail]

	Feet
Sundance Formation (part):	
Upper member (part):	
10. Sandstone, light-gray, very fine grained, well-sorted, fairly clean, limy; makes ledges separated by nonresistant gray clay; top of unit covered	8+
9. Shale, light-greenish-gray, limy, irregularly fissile or laminated; bottom-dweller trails or burrows along bedding planes; contains ostracodes; limy parts form ledges	10
8. Sandstone, light-gray, very fine grained, slightly limy, fairly well indurated; basal 1 ft forms ledge	14
7. Sandstone, light-yellowish-brown, very fine grained, well-sorted, slightly limy	5
6. Shale, olive-gray, limy; contains ostracodes	5
5. Sandstone, brownish-yellow, very fine grained, limy; lower 1 ft forms ledge	5
4. Shale, gray, limy	10

Partial section of the Sundance Formation in the SE¼ sec. 32, T. 4 N., R. 82 W.—Continued

Sundance Formation (part)—Continued	
Upper member (part)—Continued	*Feet*
3. Siltstone, gray, limy; contains sparse glauconite and biotite; interbedded with yellowish-gray limy silty sandstone; contains bottom-dweller burrow casts; forms a few ledges	8
Partial thickness, upper member	65
Lower member:	
2. Sandstone, buff to moderate-reddish-orange, very fine grained, well-sorted, friable	164
1. Sandstone, light-gray, very fine grained, well-sorted, friable; basal 1 in. is platy, gritty and shaly	2
Total thickness, lower member	166
Partial thickness, Sundance Formation	231
Chugwater Formation:	
Siltstone, moderate-reddish-brown; some parts bleached gray; micaceous thin bedded, nonresistant; sharp contact with overlying Sundance (basal 10 ft and contact with Precambrian covered)	100
Precambrian granitic rock.	

Beds 3 through 8 are probable equivalents of the Lak Member of the Sundance, and beds 9 and 10 are probably equivalents of the Pine Butte Member of the Sundance (Pipiringos, 1968).

The lower member of the Sundance lacks fossils, but there is little doubt that it correlates with the Entrada Sandstone of Late Jurassic age to the west (G. N. Pipiringos, oral commun., 1966) and with the basal sandstone member of the Sundance of Lee (1927, p. 15–16), of Jurassic age. The correlation is made on the basis of similar lithology and stratigraphic position. The member is probably equivalent to the Canyon Springs Sandstone Member of the Sundance Formation (G. N. Pipiringos, oral commun., 1966).

The upper member is correlated in part with the Curtis Formation of northwestern Colorado on the basis of similar age, lithology, and stratigraphic position. Pipiringos (1968) recognized equivalents of the Lak and his Pine Butte Member of the Sundance Formation in the Barber Basin and Frantz Creek sections, and he correlated the Pine Butte Member with the Curtis Formation. The uppermost Sundance is not exposed at Barber Basin or Frantz Creek, and it is possible that younger beds, possibly those of the Windy Hill Sandstone Member of Pipiringos (1968), are also represented. The *Camptonectes* fossils (identified by G. N. Pipiringos) found in bed 7 of the Barber Basin section are Late Jurassic marine pelecypods. The ostracodes are fresh-water forms, according to Pipiringos; the occurrence of both marine and fresh-water forms indicates some interfingering of nonmarine beds with the predominantly marine sequence.

MORRISON FORMATION

The Morrison Formation includes Upper Jurassic nonmarine beds, which conformably overlie the Sundance Formation and underlie, in part unconformably, the Dakota Sandstone of Early Cretaceous age. The formation is mostly nonresistant except for lenticular standstone beds which make weak ledges. It commonly occupies the back slope of the ridge formed by resistant beds in the Dakota Sandstone. Exposures of the formation are generally poor, and the upper part is nowhere well exposed, owing in part to cover by rubble from the overlying Dakota Sandstone. A section of the lower part was measured at Barber Basin.

The Morrison ranges in thickness from 340 feet in the Hiawatha test hole in the northeastern part of the area to about 500 feet in the DeBerard test hole in the southeastern part of the area, and it may be more than 500 feet thick in parts of the Barber Basin area to the southwest. At an outcrop in the southwest corner of the Pitchpine Mountain quadrangle, about 1½ miles north of the Teal Lake quadrangle, the Morrison is about 430 feet thick.

The Morrison Formation in southwestern North Park is similar in lithology to the Morrison in northwestern North Park. It consists predominantly of gray, green, and dark-red claystone, brown to gray calcareous sandstone, and lesser calcareous siltstone, shale, and locally, thin limestone. The basal contact with the Sundance Formation is conformable and reflects a change from marine to nonmarine deposition. The presence locally of fresh-water ostracodes in the upper part of the predominantly marine Sundance probably indicates an intertonguing relationship between the Sundance and the Morrison across a fairly narrow interval. A thin limestone bed that marks the Morrison-Sundance contact at most places in northwestern North Park is not present in this area.

As in northwestern North Park, the Morrison may be divided roughly into two parts: an upper third and a lower two-thirds.

The lower two-thirds consists of red, green, gray, or varicolored claystone and abundant sandstone beds. The sandstone is mostly light gray to light brownish gray, very fine to coarse grained, lenticular, and massive to crossbedded. In general the sandstone appears to become cleaner from north to south, having a decreasing content of clay and other rock fragments and an increasing content of quartz grains. In the Barber Basin section, a 54-foot-thick sandstone sequence in the lower part is very prominent. Conglomeratic beds, conspicuous in the lower part of the Morrison in northwestern North Park, are seemingly absent from southwestern North Park.

The upper one-third of the Morrison is apparently green or gray claystone interbedded with a minor amount of sandstone, and for the most part lacks the beds of red claystone so conspicuous in the lower part.

The following partial stratigraphic section of the Morrison was measured at Barber Basin:

Partial section of the Morrison Formation in the SE¼ sec. 17, T. 4 N., R. 82 W.

Morrison Formation (part):	*Feet*
Sandstone, light- to brownish-gray, coarse to very coarse grained, fairly well sorted, highly calcareous; contains rock fragments; crossbedded; weathers to thin, rough-surfaced slabs; resistant; forms dip slope; higher beds covered	4
Poorly exposed; mostly gray claystone becoming red in upper part; slightly silty, slightly calcareous	14
Poorly exposed; apparently all dark-red claystone	4
Sandstone, very light gray; mostly fine grained, but contains some lenses of coarse-grained sand; calcareous, clean, well-sorted, crossbedded; locally resistant; weathers to rounded ledges	13
Poorly exposed; contains some dark-red and grayish-green claystone	8
Poorly exposed; apparently dark-red claystone	5
Poorly exposed; apparently grayish-green claystone	5
Poorly exposed; mostly dark-red claystone; some grayish-green claystone, and sparse calcareous siltstone	15
Siltstone, light-greenish-gray, calcareous, clayey, shaly structure; gradational from underlying unit	4
Shale, greenish-gray, slightly calcareous, silty; becomes very silty in upper 3 ft	8
Sandstone, very light brownish gray, medium-grained, calcareous; mostly massive but some low-angle crossbedding; contains several resistant ledges	19
Sandstone, light-grayish-brown, very fine grained, calcareous	6
Claystone, olive-gray, slightly calcareous	5
Claystone, mostly dark red but contains some greenish-gray patches; slightly calcareous; also contains some thin lenses of hard very fine grained calcareous sandstone	28
Claystone, greenish-gray	2
Sandstone, light-greenish-gray, fine grained, clean, slightly calcareous, thin-bedded, apparently cross-laminated; weather out in thin slabs	1
Claystone, grayish-green, slightly silty, slightly calcareous	2
Sandstone, very light gray to light-brownish-gray, medium-grained poorly sorted; contains rock fragments; slightly calcareous; becomes cleaner and finer grained upward; low-angle crossbedding; forms a few resistant ledges	16

Partial section of the Morrison Formation in the SE¼ sec. 17, T. 4 N., R. 82 W.—Continued

	Feet
Morrison Formation (part)—Continued	
Sandstone, very light brownish gray; weathers light brown; fine to medium grained; poorly sorted; contains some clay fragments; crossbedded; forms resistant ledge	3
Sandstone, very light gray, very fine to fine grained, poorly sorted, calcareous, massive; forms resistant ledge	6
Sandstone; lower 5 ft. rusty yellow, upper part very light gray to light yellowish gray, reddish in upper 10 ft.; very fine to fine grained, poorly sorted, except well-sorted upper part; mostly nonresistant, except a few beds are slightly resistant where calcareous; massive	29
Poorly exposed; mostly gray to greenish-gray claystone, but some dark red; calcareous, locally fissile; unit also contains some moderately resistant siltstone beds, and a few small lenses of light-gray limestone	15
Siltstone, orange-brown, calcareous; locally resistant and ledge forming	2
Claystone, dark-greenish-gray	1
Siltstone, very light gray, clayey, calcareous	2
Sandstone, orange-brown, fine-grained, calcareous	1
Claystone, gray to grayish-purple	4
Sandstone, very light gray, fine-grained, clean, well-sorted, calcareous; forms thin resistant ledge	1
Sandstone, light-orange-brown, fine-grained, calcareous	2
Claystone, dark-greenish-gray	1
Sandstone, very light gray, fine-grained, clean, well-sorted, highly calcareous; curved, probably ripple bedded; contains obscure bottom-dweller trails or burrow casts; forms resistant ledge	3
Claystone, mostly greenish gray but partly purplish red; irregularly calcareous	12
Shale, medium- to dark-brownish-gray, silty to sandy, calcareous, thin-bedded to fissile	5
Sandstone, rust-brown, fine to very fine grained, calcareous; moderately resistant	2
Partial thickness, Morrison Formation	248
Sundance Formation: (NOTE: The Morrison-Sundance contact may lie within the poorly exposed unit described below.)	
Poorly exposed; most is light-greenish-gray fine to very fine grained calcareous slightly clayey sandstone	20

No fossils were found in the Morrison. The formation is generally regarded as Late Jurassic in age; but where the upper boundary is conformable with the overlying Dakota Sandstone, as it may be locally in the area, the assignment of the uppermost beds is in doubt, and they may be Early Cretaceous in age.

CRETACEOUS SYSTEM

DAKOTA SANDSTONE

The Dakota Sandstone of Early Cretaceous age overlies, in part unconformably, the Morrison Formation and conformably underlies the Benton Shale of Early and Late Cretaceous age. The Dakota is divided into a lower and upper member that may correspond to the Lytle and South Platte Formations of the Dakota Group (Waagé, 1955). The members were not divided in mapping. The lower member is mostly nonmarine sandstone and claystone; the upper member is marginal marine and nonmarine sandstone, siltstone, claystone, and shale.

The Dakota is the most resistant formation in the sedimentary sequence, and its sandstone beds commonly form cliffs, scarps, ledges, or dip slopes. The dominant topographic expression of the Dakota is a prominent hogback ridge which is generally capped by a resistant sandstone bed in the upper member. The Dakota locally forms part of the Continental Divide at Rabbit Ears Pass. The formation is fairly well exposed in much of its outcrop area, but in many places the abundant rubble from its resistant sandstone beds obscures its less resistant beds and the contact with the underlying Morrison Formation. Shale or other nonresistant beds near the top of the Dakota are in many places absent owing to erosion from a dip slope. The Dakota is a major constituent of three large block slides.

The Dakota ranges considerably in thickness. Complete surface sections could not be measured in the northern two-thirds of the area because the upper beds have been removed by erosion. Figure 2 shows seven stratigraphic columnar surface sections of the Dakota measured in and near the mapped area. Thicknesses observed in drill holes range from about 100 feet in the DeBerard test hole in the southeastern part of the area to about 200 feet in the Hiawatha test hole in the northeastern part of the area. The section in the DeBerard test hole is anomalously thin in view of the fact that the Dakota may be as much as 170 feet thick in the nearby Walters test hole. Other drill-hole thicknesses of the Dakota are: about 175 feet in the Pony Creek test hole in the northwestern part of the area and about 140 feet in the Buffalo Creek test hole in the northeastern part of the area. The thickest Dakota section was measured near Colorado Creek just outside the mapped area in sec. 32, T. 6 N., R. 82 W., about a quarter of a mile west of the Rabbit Ears Peak quadrangle. Here a partial thickness of the Dakota is 243 feet; upper beds are missing. The only complete surface section to be measured within the area was at Muddy Creek where the Dakota is

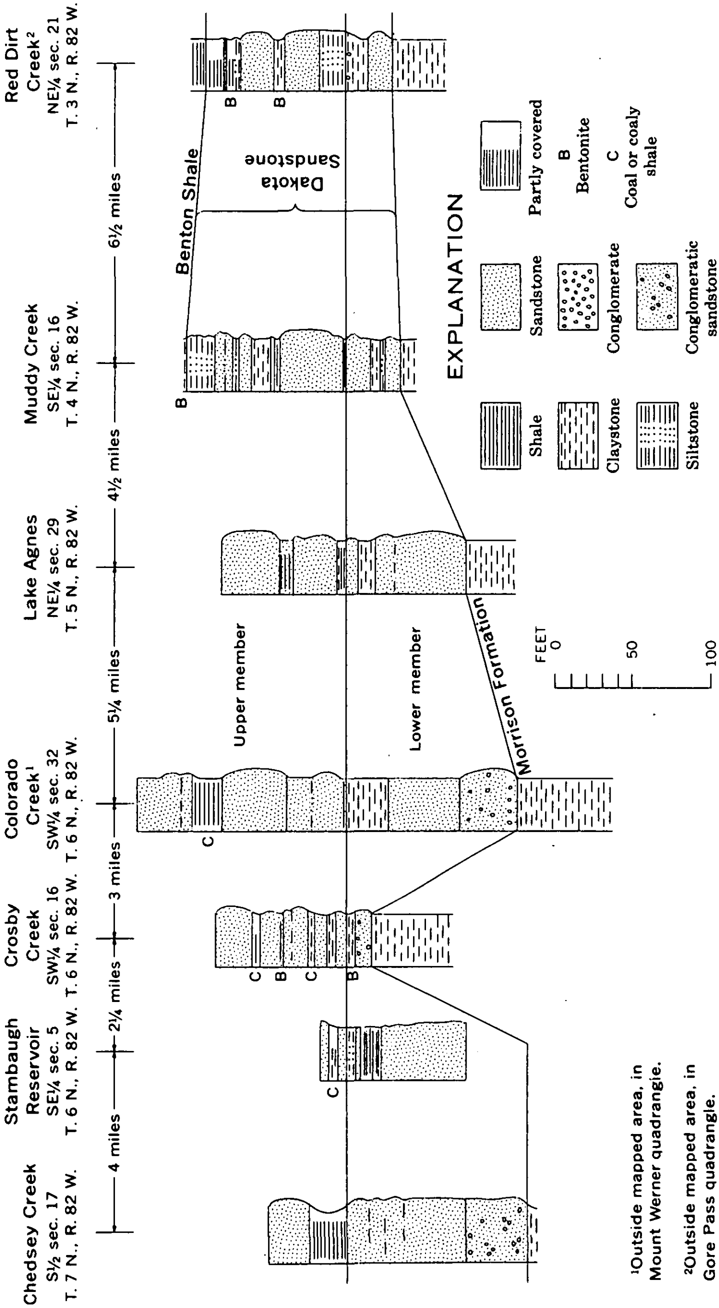

FIGURE 2.—Columnar measured sections of the Dakota Sandstone.

only about 140 feet thick. It thins to 120 feet farther south in a section measured near Red Dirt Creek about 6½ miles south of the Muddy Creek section, outside the mapped area.

LOWER MEMBER

The lower member of the Dakota consists of nonmarine claystone and siltstone, sandstone, conglomerate, and conglomeratic sandstone. The beds of claystone and siltstone are light gray, or light grayish green, and locally red. The beds of sandstone are light gray to light brownish gray and fine to coarse grained. Bedding is mostly massive or crossbedded, rarely even bedded. The conglomerate and pebbly beds are lenticular. In some places conglomerate beds are present, elsewhere equivalent beds may contain a sparse scattering of pebbles, or none at all. Crossbedding is more conspicuous in the pebbly beds. Most of the pebbles are of stream-rounded chert or quartzite and mostly range in length from ¼ to 1 inch. The sandstone and conglomerate beds are moderately to strongly resistant but generally do not form the prominent scarps or cliffs like those of the sandstone of the upper member. In the northern part of the area, the claystone or siltstone beds, where present, overlie the sandstone or conglomerate beds and form the upper part of the member. In the southern part of the area, however, claystone is locally overlain by sandstone.

In northwestern North Park and in the northern part of the area of this report, the contact of the Dakota and Morrison is sharp and apparently unconformable. Conglomerate and sandstone occur in channels cut into the Morrison, and at many places the contact is marked by a conspicuous weathered zone at the top of the Morrison. Southward, however, indications of unconformity are not as clear, although nearly everywhere there is a fairly abrupt change from gray or green claystone of the upper part of the Morrison to abundant sandstone, mapped as Dakota.

The thickness of the lower member in measured surface sections is highly variable and ranges from 17 to 116 feet (fig. 2). The variation may be due both to deposition on an irregular or channeled surface of Morrison and to erosion prior to deposition of the upper member.

UPPER MEMBER

The upper member of the Dakota consists mostly of interbedded gray to black shale or claystone, light-gray to light-brown sandstone, and siltstone, probably deposited in a marginal marine environment.

The upper member may be divided into three parts. The lower part consists chiefly of interbedded sandstone and subordinate dark-gray to black shale or claystone. The sandstone is mostly light gray to light

298-047 O—68——4

grayish brown, fine grained, clean, and even bedded or massive and locally crossbedded. Most is hard and resistant and forms cliffs. Much of the sandstone of the lower part is ripple marked and contains abundant casts of bottom-dweller burrows or trails. Some contains much carbonaceous material in the form of disseminated fragments, films on bedding laminae, and carbonized plant fragments. The claystone of the lower part is dark gray to black, silty to clayey, and mostly nonresistant and ranges from fissile to blocky. Locally it contains coal or coaly shale and thin bentonite beds. A persistent dark shale or claystone bed marks the top of the lower part and serves as a useful marker bed.

The middle part of the upper member is sandstone or interbedded sandstone and siltstone and locally thin beds of shale. The sandstone is light gray to medium brown, fine to medium grained, clean, and even bedded but locally massive or obscurely crossbedded. It weathers to various shades of gray, brown, and pink and commonly weathers to rectangular blocks or slabs, many of which have ripple-marked surfaces. This sandstone is very hard and resistant and is the strongest and most persistent hogback-forming unit in the area. In most places erosion has removed the higher beds and left a long dip slope. Locally, as at the north end of the ridge 1 mile southwest of Lake Agnes, the sandstone is quartzitic.

The upper part of the upper member is marine siltstone interbedded with, or grading laterally to, gray or black carbonaceous silty claystone. It contains abundant fish scales and also carbonaceous material including plant fragments. The lower contact of the unit is sharp and apparently unconformable. In the Muddy Creek section the base of the upper unit of the upper member is marked by a thin conglomerate bed. The unit grades upward to the marine Mowry Shale Member of the Benton Shale. In northwestern North Park the contact between the equivalent of this unit and lower strata of the Dakota is gradational and conformable. The extent of the unconformity at the base of the unit as seen at Muddy Creek is not known.

The basal contact of the upper member of the Dakota with the lower member is sharp except in the Red Dirt Creek section (fig. 2) south of the mapped area. The contact is placed at the base of the first bed overlying the light-gray or green claystone of the lower member, or the base of the lowest dark shale, where claystone is absent. Evidence of unconformity between the two members is not clearly established within the mapped area, but is suggested by the sharp contact seen at individual outcrops, by the variation in thickness of the lower member which may indicate, in part, erosion of its upper beds, and by the absence of interfingering at the contact.

The thickness of the upper member is not well known owing to the absence of its upper beds in many places. It may be as much as 130 feet thick in the Hiawatha test hole in the northeastern part of the area, and is about 75 feet thick in the Pony Creek and Buffalo Creek test holes. It is about 100 feet thick in the Walters test hole, in the southeastern part of the area, and is 104 feet thick in the Muddy Creek surface section in the southwestern part of the area.

The following partial stratigraphic section of the Dakota Sandstone was measured a quarter of a mile south of Crosby Creek:

Partial section of the Dakota Sandstone in the SW¼ sec. 16, T. 6 N., R. 82 W.

[Approximate location in an unsurveyed township]

	Feet
Dakota Sandstone (part):	
Upper member (part):	
Sandstone, medium-brown; weathers light gray to light brownish-gray; fine to medium grained, clean, well sorted, thin bedded, cross laminated; irregular, possibly ripple marked bedding surfaces on weathered-out slabs; uppermost bed weathers to rectangular blocks; hard and resistant; forms scarp and dip slope from which higher beds have been eroded	23
Mostly covered; apparently fine-grained sandstone and interbedded coaly shale or shaly coal	5
Sandstone, light-yellowish-gray to brown, fine-grained, well-sorted, even-bedded, cross-laminated; weathered bedding surfaces are irregular, probably ripple marked; abundant bottom-dweller trails and burrows; hard and resistant; forms scarp	9
Sandstone, very light yellowish-gray to light-brown, fine-grained; contains thin carbonaceous shale partings; thin, even-bedded, cross laminated; irregularly weathered bedding surfaces; contains conspicuous bottom-dweller markings associated with carbonaceous layers	4
Shale, medium-gray to very dark-gray, silty in upper part, bentonitic	1
Bentonite, light-yellowish-gray	1
Sandstone, very light-gray, fine-grained, irregularly even-bedded, finely laminated; minor carbonaceous material on bedding planes; upper part contains carbonaceous clay with bottom-dweller markings; uppermost bed is rusty weathering cross-laminated sandstone; moderately resistant	5
Claystone, dark-gray to black, slightly silty	1
Sandstone, light-brownish-gray to dark-brown, or black where carbonaceous; weathers light brownish gray; very fine grained; contains abundant carbonaceous and coaly layers, and carbonaceous trash along bedding planes; even bedded, cross laminated, ripple marked; weathers to sharp rectangular blocks; hard and resistant; forms scarp	11

Partial section of the Dakota Sandstone in the SW¼ sec. 16, T. 6 N., R. 82 W.—Continued

	Feet
Dakota Sandstone (part)—Continued	
Upper member (part)—Continued	
Coal, black, shaly	½
Claystone; medium gray near base to light brownish gray at top; weathers light gray and light rusty brown, slightly silty	3
Sandstone, very light gray; weathers light yellowish brown and rusty yellow; very fine grained, clean, well sorted, massive; weathers to irregularly shaped blocks	8
Claystone; mostly medium gray, except light gray at top and base; silty in basal part	5
Sandstone, light-brownish-gray, fine-grained, clean, well-sorted, even-bedded; weathers to crudely rectangular blocks; hard and resistant; forms local ledge	7
Partial thickness (rounded), upper member	83
Lower member:	
Claystone, pale-green, slightly silty	1
Claystone, red	1
Claystone, pale-green, silty in lower part, probably bentonitic	2
Bentonite, very light gray, nonswelling	2
Sandstone, light-brown, except for basal 1–2 in. which is rusty brown; medium grained with some coarse pebbly sand; mostly massive, but indistinctly even bedded in the finer parts; coarse to pebbly parts show crossbedding; pebbles are chert and quartzite, mostly less than ¼ in. long; uppermost 2 ft is the most conglomeratic; unit is moderately resistant; forms weak ledge	11
Total thickness, lower member	17
Partial thickness, Dakota Sandstone	100
Morrison Formation:	
Clay, light-green to medium-gray	50+

The following partial stratigraphic section of the Dakota Sandstone was measured about 1¼ miles northwest of Lake Agnes:

Partial section of the Dakota Sandstone in the NE¼ sec. 29, T. 5 N., R. 82 W.

	Feet
Dakota Sandstone (in part):	
Upper member (in part):	
Sandstone, light-gray to light-brown; weathers various shades of brown, gray, rust, and pink; medium grained, clean, well sorted, massive to crossbedded, very hard, resistant; forms caprock cliff and dip slope from which higher beds have been eroded	37
Poorly exposed; interbedded shale and siltstone, or very fine grained sandstone; shale is clayey, black, fissile; sandstone is light gray, carbonaceous, resistant	9

Partial section of the Dakota Sandstone in the NE¼ sec. 29, T. 5 N., R. 82 W.—Continued

	Feet
Dakota Sandstone (in part)—Continued	
Upper member (in part)—Continued	
Sandstone, light-gray; weathers rusty; contains streaks of carbonaceous material	1
Sandstone, light-brown, very fine grained; contains fairly abundant limonite grains; thick, even bedded; some thin bedding in lower few feet; weathers to irregular, probably ripple-marked surfaces; contains fairly abundant bottom-dweller trails and burrows	10
Sandstone, light-gray to light-brown near top; color somewhat mottled by carbon-streaked bedding planes; very fine grained; even bedded, ripple laminated; weathers out in thin slabs; contains abundant bottom-dweller trails and burrows, and fairly abundant carbonaceous stem imprints; hard, resistant; forms cliff; base covered	14
Sandstone, mottled-gray and light-brown, very fine grained, carbonaceous, silty, clayey; carbonaceous material occurs along finely laminated bedding planes	6
Claystone, brown to black, silty, carbonaceous, finely laminated; grades to overlying unit	2
Shale, black; weathers to fissile chips	3
Partial thickness, upper member	82
Lower member:	
Claystone, brownish-gray; capped by 3 in. of rusty impure sandstone	1
Sandstone, light-brownish-gray; weathers light brown, rust, and gray; very fine to fine grained, clean, poorly sorted; bedding obscure but some weathered slabs are conspicuously crossbedded; weathers out in irregular, rough-surfaced slabs; top 2–3 in. is fine-grained rusty sandstone; moderately resistant	6
Claystone, brownish-gray, sandy	1
Sandstone, light-gray, weathers light brown; medium grained, clean, well sorted, crossbedded; forms locally resistant ledge	1
Covered interval; float in lower part is light-greenish-gray claystone	11
Sandstone, very light gray, fine- to medium-grained, poorly sorted, clean; lower few feet massive; higher beds weather out in rough but apparently even bedded slabs; irregularly resistant; forms local cliff	12
Claystone, light-green, sandy; contains quartz grains and rock fragments; top 3 in. conspicuously rusty	1
Sandstone and minor thin layers of green sandy claystone; sandstone is rusty brown, fine to medium grained, clayey	3

Partial section of the Dakota Sandstone in the NE¼ sec. 29, T. 5 N., R. 82 W.—Continued

Strike offset 300 ft to the north

	Feet
Dakota Sandstone (in part)—Continued	
Lower member—Continued	
Sandstone, very light gray, medium-grained; contains sparse but conspicuous grains of white clay and very sparse small siltstone pebbles; massive to crossbedded; moderately resistant; weathers out to rounded benches; top obscured by rubble; contact with Morrison covered	43
Total thickness, lower member	79
Partial thickness (rounded), Dakota Sandstone	160
Morrison Formation:	
Claystone, greenish-gray	30+

The following stratigraphic section of the Dakota Sandstone was measured just north of Muddy Creek:

Section of the Dakota Sandstone in the SE¼ sec. 16, T. 4 N., R. 82 W.

	Feet
Benton Shale (Mowry Shale Member):	
Claystone, very dark gray; weathers light greenish gray and brown; silty; irregularly thin, even bedded; contains abundant fish scales	2+
Bentonite, light-brownish-yellow	½
Dakota Sandstone:	
Upper member:	
Siltstone, light- to dark-gray to light-brownish-gray; carbonaceous in lower part; contains abundant fish scales, sparse plant imprints, and other carbonaceous trash; irregularly bedded, very hard and resistant; some parts finely cross laminated; weathers out to irregular thin flaggy ledges	18
Sandstone, light-gray to light-brownish gray, very fine grained, slightly carbonaceous, silty, conglomeratic; contains quartz and chert pebbles and granules as much as ½ in	1
Offset about 1,500 ft to the west	
Sandstone, light-brownish-gray, fine-grained, clean, well-sorted; contains sparse fairly large (as much as 2–3 in.) pebbles or pods of silicified dark claystone; massive; very hard and resistant; forms cliff and dip slope	6
Siltstone, light-grayish-brown; weathers light gray; clayey, slightly carbonaceous	1
Sandstone, very light gray, very fine grained, clean; abundant white clay cement; thick, even bedded, finely cross-laminated; very hard and resistant; forms cliff	5
Siltstone, very light gray, clayey, interbedded with very light gray, very fine grained, finely laminated, even-bedded sandstone; moderately resistant	3

Section of the Dakota Sandstone in the SE¼ sec. 16, T. 4 N., R. 82 W.—Continued

	Feet
Dakota Sandstone—Continued	
Upper member—Continued	
Sandstone, light-gray to light-brownish-gray, silty, clayey; clean except for strong clay cement, and carbonaceous laminae; even bedded, finely cross laminated; lower part massive and contains considerable carbon plant trash; hard and resistant; forms rough-faced cliff	8
Strike offset about 1200 ft. to the northeast	
Claystone, black; weathers out in irregular to fissile fragments	13
Sandstone, light-gray, very fine grained; strong clay cement; contains carbonized leaf fragments; contains a few thin clayey interbeds; massive to thick, even bedded; some ripple marking and sparse bottom-dweller markings; hard and resistant; forms ledge	2
Shale, black, blocky to fissle, brittle; contains carbonized plant fragments on some bedding planes	4
Sandstone, light-grayish-brown; weathers light brownish gray; very fine grained to silty, slightly carbonaceous; contains some carbonized plant fragments on some laminae; even bedded; finely cross laminated; jointed; resistant; forms square-faced blocky cliff	9
Sandstone, very light brownish gray, fine- to medium-grained, well-sorted; strong white clay cement; obscurely crossbedded; weathers out along fractures and joints; very hard and resistant; forms cliff	12
Sandstone, light-gray; weathers light brownish gray to rusty brown, very fine grained; contains very thin siltstone and claystone interbeds; thin, wavy, even bedded; ripple marked; contains abundant bottom-dweller trails and burrows; sparse carbonaceous material on bedding planes; very hard and resistant; forms rough-faced cliff	15
Sandstone, light-gray; weathers very light gray; very fine grained; contains abundant thin black shale, silty claystone, or carbonaceous material on bedding planes; thin, wavy, even bedded; ripple marked; contains abundant bottom-dweller trails and burrows; moderately resistant	6
Shale, very dark gray to black; weathers thin bedded to fissile; contains carbonized plant imprints	3
Total thickness, upper member	106
Lower members:	
Sandstone, light-brownish-gray; weathers rusty brown; very fine to medium grained, poorly sorted, massive, friable but resistant; forms ledge	8

Section of the Dakota Sandstone in the SE¼ sec. 16, T. 4 N., R. 82 W.—Continued

Strike offset 110 ft. to the south

	Feet
Dakota Sandstone—Continued	
Lower member—Continued	
Poorly exposed; basal part and top is sandstone which is light brownish gray, fine grained, and well sorted, and which is cemented by weak white clay; nonresistant	8
Claystone, pale-green; weathers greenish brown, silty; weathered rusty at top	6
Siltstone, light-gray, clayey	3
Sandstone, light-brownish-gray, very fine grained, clean, well-sorted; contains grains of white clay; massive, friable, moderately resistant; forms weak ledge	8
Sandstone, light-brown; weathers light gray; fine grained, well sorted, nonresistant	5
Total thickness, lower member	38
Total thickness, Dakota Sandstone	144
Morrison Formation:	
Poorly exposed; mostly pale green slightly silty claystone	15+

Correlation.—The Dakota Sandstone is equivalent to the Dakota Group as defined by Waagé (1955) on the east flank of the Front Range. It correlates with the Dakota Sandstone in the Glenwood Springs area, 40 miles to the southwest of this area, as used by Bass and Northrop (1963, p. J55). Its lower member is probably in part equivalent to the Burro Canyon Formation of southwestern Colorado, in which area the name Dakota is used but is restricted to beds equivalent to the upper member of this area. The name Dakota is also restricted by many workers to equivalents of the upper member where they use the name Fuson for both nonmarine and marine claystones and shales between sandstone of the lower and upper members, and the name Lakota for the sandstone and conglomerate beds of the lower member. The upper part of the upper member correlates with the Muddy Sandstone Member of the Thermopolis Shale of Wyoming.

BENTON SHALE

The Benton Shale of Early and Late Cretaceous age consists of marine beds conformably overlying the Dakota Sandstone, and underlying with possible disconformity, the Niobrara Formation. The Benton is divided for purposes of description into three members, in ascending order, the Mowry Shale Member, the middle shaly member, and the Codell Sandstone Member. A possible disconformity separates the middle shaly member from the Codell Sandstone Member. These members were not mapped separately.

The middle shaly member of the Benton, which composes most of the formation, is very soft and nonresistant and forms valleys and covered slopes; nowhere is it completely exposed. The Mowry Shale Member is fairly resistant but is dominated topographically by the more resistant Dakota Sandsone, and the Mowry commonly is present at the foot of a Dakota dip slope, considerably obscured by rubble stripped from the dip slope. The Codell Sandstone Member at the top of the Benton is resistant and forms a thin but strong ridge or hogback throughout much of its outcrop area.

The Benton ranges in thickness from about 420 to 460 feet in drill holes, but may be more than 500 feet thick along Muddy Creek, where a partial surface section was measured.

The Mowry Shale Member consists of dark-gray silty thin-bedded to fissile shale, commonly weathering out to small flat light-gray chips. Fish scales are present in most beds. The shale is interbedded with minor thin beds of bentonite. The Mowry is moderately resistant relative to the overlying middle shaly member. It lies conformably on the underlying Dakota Sandstone and its lower beds are gradational from the resistant siltstone of the Dakota to the dark silty shale typical of the Mowry. Locally, as at the Muddy Creek measured section, the contact is placed at the base of a bentonite bed in the transitional sequence. Elsewhere, in areas of poor exposure, the contact is difficult to place, but generally can be determined within 5–15 feet stratigraphically. The Mowry is about 100 feet thick in the Muddy Creek measured section and ranges in thickness from 100 to 125 feet in drill holes.

The middle shaly member is nearly everywhere poorly exposed. It is black to dark-brownish-gray shale ranging from noncalcareous shale in the lower part to highly calcareous shale in the upper part. Its lower beds are soft black fissile shale, interbedded with thin beds of bentonite, and containing sparse but conspicuous bluish-black ironstone concretions which fracture easily and litter exposed slopes with small fragments of the ironstone. The contact of the middle shaly member with the Mowry Shale Member is gradational and is characterized by a decreasing silt content in the transitional zone. The middle part of the middle shaly member is nowhere exposed but is probably nonresistant dark-gray to brown silty shale, becoming more silty and calcareous upward. The uppermost 5 feet of the middle shaly member is highly calcareous and resistant and contains the fossils *Inoceramus pictus* Sowerby, and *Astarte* n. sp., identified by W. A. Cobban who said of them: "These fossils occur in the lower and middle parts of the Greenhorn Limestone in the Great Plains area." The equivalence of these beds with the lower and middle parts of the Greenhorn, and the sharp break at the top of the middle shaly member suggest that beds equivalent to the upper part of the Greenhorn may be absent because

298-047 O—68——5

of erosion. The middle shaly member apparently ranges from 290 to as much as 350 feet in thickness.

The Codell Sandstone Member consists of interbedded calcareous sandstone, calcarenitic limestone, shale, and siltstone. The lower two-thirds of the Codell is a very resistant unit consisting of light-brown and brownish-gray interbedded sandstone and limestone. Some of the limestone beds are characterized by a content of abundant fossil shells, mostly broken fragments, and a petroliferous odor from freshly broken surfaces. The uppermost bed in the lower part is very hard and resistant and commonly forms the cap rock for a low ridge, which characterizes the Codell along much of its outcrop. This bed yielded the following fossils, identified by W. A. Cobban: *Inoceramus dimidius* White, *Scaphites warreni* Meek and Hayden, and *Prionocyclus wyomingensis* Meek. The upper one-third of the Codell consists predominantly of nonresistant silty calcareous shale and thin beds of nonresistant shaly siltstone and calcarenite limestone. This unit is rarely exposed. The lowermost 2 feet of this upper part yielded the following fossils, identified by W. A. Cobban: *Inoceramus perplexus* Whitfield and *Scaphites whitfieldi* Cobban. The basal contact of the Codell on the middle shaly member is very sharp and may represent a disconformity (fig. 3). The Codell Sandstone Member ranges from about 30 to 60 feet in thickness.

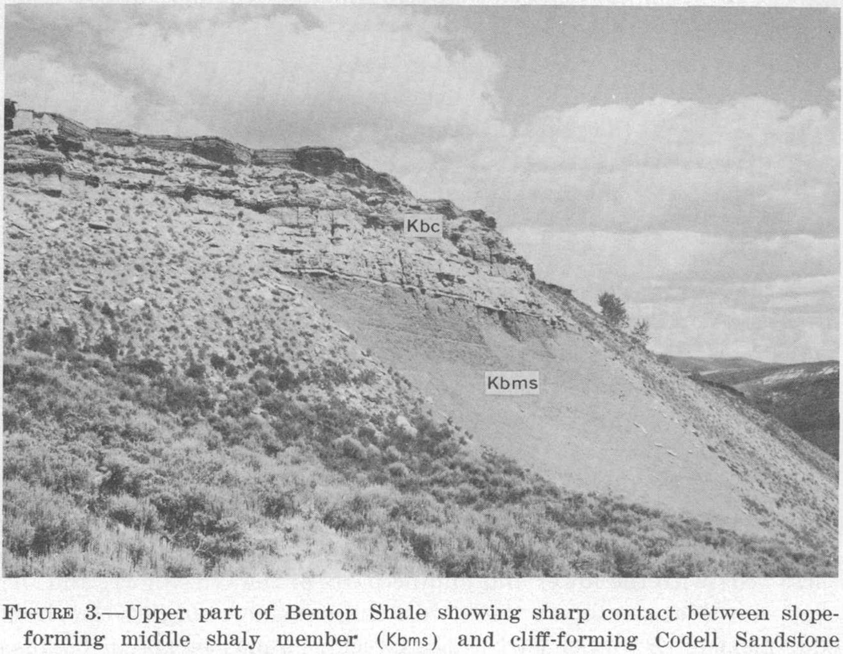

FIGURE 3.—Upper part of Benton Shale showing sharp contact between slope-forming middle shaly member (Kbms) and cliff-forming Codell Sandstone Member (Kbc). Cliff is about 40 feet high. SE1/4 sec. 15, T. 4 N., R. 82 W., just north of Muddy Creek.

The following stratigraphic section of the Mowry Shale Member of the Benton Shale was measured along the north bank of Muddy Creek:

Section of Mowry Shale Member of the Benton Shale in the W½ sec. 15, T. 4 N., R. 82 W.

	Feet
Benton Shale (part):	
Middle shaly member (part):	
Shale, very dark gray to black; weathers light to medium gray in lower part which is silty	10+
Bentonite, very light yellowish gray. This bed is arbitrarily selected as the base of the middle shaly member of the Benton, inasmuch as it constitutes a marker bed within a transition zone grading from light-gray-weathering silty shale of typical Mowry lithology below, to black-weathering nonsilty shale typical of the middle shaly member above	2
Mowry Shale Member:	
Shale, very dark gray to black; weathers medium to light gray; slightly silty to nonsilty; fissile, moderately brittle; contains fish scales; conspicuous vertical jointing	9
Shale, dark-gray, silty; contains thin interbeds of shaly siltstone and bentonite	2
Bentonite, light-grayish-green to gray	1½
Shale, very dark gray; weathers medium to light gray and rusty brown; silty in upper part; contains fish scales; fissile, brittle; contains 2-in. bentonite bed 2½ ft below top	6
Shale, very dark brown, silty, possibly bentonitic	½
Bentonite, light-grayish-green to medium-gray, indistinct shaly structure	5
Strike offset 200 ft to the west	
Shale, very dark gray to black; weathers light bluish gray; silty; contains fish scales and carbonaceous fragments; thin bedded to fissile; brittle; contains a few bentonite stringers	4
Shale, medium-light-brown, silty, bentonitic; contains brown carbonaceous imprints	1
Shale; interbedded black nonsilty fissile clay shale and black slightly silty shale; siltier parts are more resistant	3
Bentonite, very light yellowish gray, impure; contains black shale parting	½
Shale, very dark gray to black; weathers light bluish gray; becomes less silty, less resistant, and contains fewer siltstone interbeds than beds lower in the section; fissile; weathers to thin fissile chips; contains a few beds of very thin bentonite less than 2 in. thick	20
Covered interval; apparently shale like underlying unit	4
Shale, very dark gray to black; weathers light gray; slightly silty; contains abundant fish scales; thin, even bedded to fissile; contains sparse fine silt laminae; contains thin beds of silty shale, which form resistant ledges, and thin beds of bentonite less than 2 in. thick	6
Covered interval; probably shale as in overlying unit	10
Shale, black, weathers brown; bentonitic	½
Bentonite, light-grayish-yellow; contains 4-in. bed of black shale 1 ft above base	2

Section of Mowry Shale Member of the Benton Shale in the W½ sec. 15, T. 4 N., R. 82 W.—Continued

Strike offset about 200 ft to the west

	Feet
Benton Shale (part)—Continued	
Mowry Shale Member—Continued	
Shale, very dark gray to black, except silty parts are medium to light gray; weathers light gray; contains abundant fish scales; even, thin bedded to fissile	2
Claystone, grayish-brown, silty	2
Shale, very dark gray to black, weathers light gray; slightly silty; contains abundant fish scales and sparse bones; even, thin bedded to fissile; weathers to flat fissile, brittle chips, contains a few bentonite stringers	9
Bentonite, yellowish-gray	½
Shale, very dark gray to black, weathers light gray; slightly silty; contains abundant fish scales; even bedded; weathers to fissile, brittle chips; contains sparse bentonite stringers	4
Bentonite, yellowish-brown	½
Shale, very dark gray to black; weathers light gray; slightly silty; contains fish scales; fissile	1
Bentonite, yellowish-brown	½
Shale, very dark gray to black, except siltier parts, which are medium to light gray; silty; contains abundant shaly siltstone interbeds in lower few feet; contains abundant fish scales and sparse fish bones; flat, even, thin bedded, fissile, brittle	7
Bentonite, light-yellowish-gray	1
Total thickness (rounded), Mowry Shale Member	103
Dakota Sandstone:	
Siltstone, light- to dark-gray and light-brownish-gray; contains abundant fish scales and sparse carbonized plant fragments; irregularly even, thin bedded, finely cross laminated with carbonaceous coatings on some laminae; hard and resistant	1+

The following partial stratigraphic section of the middle shaly member of the Benton Shale was measured just north of Muddy Creek:

Partial section of the middle shaly member of the Benton Shale in the NW¼ sec. 15, T. 4 N., R. 82 W.

	Feet
Benton Shale (part):	
Middle shaly member (part):	
Poorly exposed; mostly black fissile shale; contains at least one bentonite bed less than ½ ft thick near middle of unit	18
Bentonite, light-yellowish-gray	½
Shale, black; weathers bluish black; fissile, soft	8
Bentonite, light-gray, impure, silty	½
Shale, black; contains fish scales and bones; fissile, soft	15
Bentonite, light-yellowish-gray	½

Partial section of the middle shaly member of the Benton Shale in the NW¼ sec. 15, T. 4 N., R. 82 W.—Continued

	Feet
Benton Shale (part)—Continued	
Middle shaly member (part)—Continued	
Poorly exposed; shale, black; contains fish scales and bones; fissile, soft; contains scattered dark-bluish-gray bluish-black weathering oval concretions as much as 3 ft in diameter; these are noncalcareous except on fracture surfaces, where they are calcareous very heavy, dense, easily fractured, probably sideritic ironstone; ironstone fragments are abundant	16
Bentonite, light-yellowish-gray	½
Strike offset 50 ft to the north across gully	
Shale, black; weathers gray to black; contains fish scales and bones; fissile, soft; upper two-thirds poorly exposed; contains at least one thin bentonite bed in upper part	22
Shale, black; weathers light to dark gray; resistant silty ledge forms top of unit	6
Bentonite, light-yellowish-gray	2
Shale, black; weathers light to dark gray; slightly silty; contains sparse fish scales; fissile; base of measured section at creek level; lower beds covered	7
Partial thickness	96

The estimated thickness of strata below the base of this measured section and above the highest bed of the Mowry Shale Member measured section at Muddy Creek is about 50 feet, all of which is in the middle shaly member and, as indicated from surface wash, is probably shale and thin beds of bentonite like the section described above. The estimated thickness of strata above this measured section and the base of the next measured section, which includes the upper part of the middle shaly member and the Codell Sandstone Member, is about 150–200 feet.

The following stratigraphic section of parts of the middle shaly member and Codell Sandstone Member of the Benton Shale was measured just north of Muddy Creek:

Partial section of middle shaly member and Codell Sandstone Member of the Benton Shale in the SE¼ sec. 15 and the SW¼ sec. 14, T. 4 N., R. 82 W.

	Feet
Benton Shale (part):	
Codell Sandstone Member (part):	
Interbedded silty shale and shaly siltstone, highly calcareous; becomes more silty and calcareous, less clayey upward; thin limestone (calcarenite) beds in upper part; thin, even bedded to fissile. The top of this unit is covered in slumped ground but is probably within 10 ft. stratigraphically of the base of the Fort Hayes Limestone Member of the Niobrara Formation which in this vicinity is fine-grained light-gray silty limestone	7

Partial section of middle shaly member and Codell Sandstone Member of the Benton Shale in the SE¼ sec. 15 and the SW¼ sec. 14, T. 4 N., R. 82 W.—Continued

Strike offset 400 ft. to the southwest

Benton Shale (part)—Continued	
Codell Sandstone Member (part)—Continued	*Feet*
Shale, dark-gray, calcareous, slightly silty; contains a few very thin beds of grayish-brown limestone (calcarenite), also contains a few very thin standstone beds; grades to overlying unit	7
Limestone (calcarenite) and thin interbedded shale; limestone is grayish brown, contains abundant fossil shell fragments, and has a petroliferous odor; shale is dark gray to black, even bedded to fissile. Fossil collection USGS Mesozoic loc. D3888 (pl. 3, fossil loc. 3): *Inoceramus perplexus* Whitfield and *Scaphites whitfieldi* Cobban	2

Strike offset 1,700 ft. to the northwest

Limestone (calcarenite), light-grayish-brown, weathers light brown; contains fossil shells and abundant shell fragments; even bedded; finely cross laminated; weathers out to crinkly slabs 1–4 in. thick; petroliferous odor on freshly broken surface; very hard and resistant; main ridge-forming unit of Codell; fossil collection USGS Mesozoic loc. D3887 (pl. 3, fossil loc. 2): *Inoceramus dimidius* White, *Scaphites warreni* Meek and Hayden, *Prionocyclus wyomingensis* Meek	5
Sandstone, light-grayish-brown, very fine grained, highly calcareous; contains carbonaceous material on bedding planes; even, thin bedded to fissile; contains fossil shell fragments; nonresistant	4
Limestone (calcarenite), light-grayish-brown; sparse clay on bedding surfaces; petroliferous odor on freshly broken surface; contains abundant fossil shell fragments; hard and resistant; forms strong ledge	1
Sandstone, light-brownish-gray to light-brown; weathers light brownish gray; very fine grained, highly calcareous; contains clay or carbonaceous material on bedding planes; even, thin bedded to fissile; finely cross laminated; contains at least two thin beds of hard limestone; uppermost 6 in. contains hard spheroidal limestone concretions 6–9 in. in diameter	2
Limestone (calcarenite), medium-grayish-brown; petroliferous odor on freshly broken surface; abundant fossil shell fragments; moderately resistant	1
Sandstone, light-brown to light-brownish-gray, very fine grained, highly calcareous; contains clay and carbonaceous material on bedding planes; even, thin bedded to fissile, finely cross laminated	1
Sandstone, light-brownish-gray; weathers light brown; highly calcareous; thin, even bedded; resistant; forms strong ledge	1

Partial section of middle shaly member and Codell Sandstone Member of the Benton Shale in the SE¼ sec. 15 and the SW¼ sec. 14, T. 4 N., R. 82 W.—Continued

Strike offset 1,700 ft. to the northwest—Continued

	Feet
Benton Shale (part)—Continued	
Codell Sandstone Member (part)—Continued	
Sandstone, light-brown to light-brownish-gray, very fine grained; highly calcareous; contains carbonaceous material on some bedding planes; even, thin bedded to fissile; finely cross laminated; contains a few thin beds of hard limestone (calcarenite) in upper part	5
Limestone (calcarenite), medium- to light-brownish-gray; irregularly even, thin bedded to fissile; contains at least one 3-in. bed of sandstone; weathers out to irregular or crinkly slabs; contains abundant fragments of fossil shells; resistant; forms ledge	2
Sandstone, light-grayish-brown, calcareous, fine-grained; even bedded, finely cross laminated; contains clay coatings on laminae; contains 1 in. of fissile black shale at top, sharp contact with underlying unit	1
Sandstone, mottled-dark-brownish-gray to light gray; very fine grained, clayey, noncalcareous; contains clay and carbonaceous material on bedding planes and as irregular disseminations; massive but from a distance appears vaguely even bedded	4
Sandstone, light-brownish-gray and mottled-gray, dark-grayish-green and brown, very fine grained, poorly sorted, impure; clayey; clay occurs as layers on bedding planes, most of which are cross laminated; unit as a whole is even, thin bedded; contains sparse dark fissile shale interbeds, some of which are calcareous and resistant and form strong ledges at 2, 4, 5½, and 8 ft. above the base; contact with underlying unit it sharp	11
Shale, very dark brownish gray to black; contains thin yellow laminae	1
Sandstone, light-brownish-gray, very fine grained, calcareous; contains conspicuous and abundant bottom-dweller trail and burrow casts; even bedded; hard and resistant; forms strong ledge; very sharp contact with underlying unit	1
Total thickness, Codell Sandstone Member	56
Middle shaly member (part):	
Shale, dark-gray to black in lower part, becoming dark gray to brownish gray in upper part; slightly calcareous, becoming more calcareous and more silty upward; upper 5 ft. very calcareous, almost a clayey limestone which is moderately resistant; unit contains a few conspicuous flattened oval limestone concretions ranging from a few inches to 1 ft. in diameter (the smaller ones resemble stream pebbles); fairly abundant crystalline gypsum on weathered bedding surfaces; contains abundant microfossil specks and fairly abundant small shells; fossil collection USGS Mesozoic loc. D3886 (pl. 3, fossil loc. 1): *Inoceramus pictus* Sowerby and *Astarte* n. sp	13

Partial section of middle shaly member and Codell Sandstone Member of the Benton Shale in the SE¼ sec. 15 and the SW¼ sec. 14, T. 4 N., R. 82 W.—Continued

Benton Shale (part)—Continued	
Middle shaly member (part)—Continued	*Feet*
Bentonite, light-gray, shaly structure	½
Shale, dark-gray to black, slightly to highly carcareous, silty; contains abundant microfossil specks and small shells; thin lenticular siltstone bed 1 ft. below top	12
Bentonite, light-yellowish-gray	½
Shale, dark-gray to dark-brownish-gray, slightly to highly calcareous, silty; contains abundant microfossil specks which coat many bedding planes; contains some small shells and sparse fish scales	12
Siltstone, medium-gray, highly calcareous, lenticular, evenly laminated; hard and resistant	1
Shale, dark-brownish-gray to black; weathers medium brownish gray; slightly calcareous; abundant white powder calcite on weathered bedding planes; becomes silty in upper part; contains abundant fish scales	8
Mostly covered; apparently all dark-gray slightly calcareous shale as above; base covered by slump blocks	41
Partial thickness, middle shaly member	88

The Benton Shale of North Park correlates with the Benton Shale or with the Graneros Shale, Greenhorn Limestone, and Carlile Shale of eastern Colorado. It correlates with the lower part of the Mancos Shale of northwestern Colorado. The Mowry Shale Member correlates with the Mowry Shale of Wyoming. The middle shaly member includes equivalents of the Graneros Shale and Greenhorn Limestone of eastern Colorado, and equivalents of the lower part of the Frontier Formation of southwestern Wyoming and western Colorado. The correlation of the Codell Sandstone Member of this area with the type Codell of Kansas is not well known. It occupies the approximate stratigraphic position of the type Codell and of the Codell as commonly mapped in eastern Colorado, but the fossils and lithology of its upper part, at least, closely resemble those of the Juana Lopez Member of the Mancos Shale of northern New Mexico and southern Colorado (W. A. Cobban, oral commun., 1965), where the Juana Lopez, consisting of calcarenite limestone, overlies with possible disconformity the Codell which consists mostly of sandstone. The Codell of southwestern North Park, as measured near Muddy Creek, may contain equivalents of both the Juana Lopez and the Codell, inasmuch as the lower 16 feet consists of sandstone separated by a sharp break from the overlying 40 feet of interbedded calcarenite limestone and sandstone, but fossils are lacking in the lower part, and correlation of this part with true Codell cannot be firmly established. In western Colorado the sandy or limy beds at the top of the Frontier Formation correlate with the Codell of this area.

NIOBRARA FORMATION

The Niobrara Formation of Late Cretaceous age consists of marine calcareous shale and limestone, overlying with possible disconformity the Codell Sandstone Member of the Benton Shale, and conformably underlying the Pierre Shale. The Niobrara consists of two members, the thin basal Fort Hays Limestone Member, and the Smoky Hill Shale Member. The two members were not mapped separately.

The Niobrara is mostly nonresistant and commonly forms easily eroded lowlands or slopes, although relatively resistant limestone beds locally make low hogback ridges north of Muddy Creek. It is identified in areas of poor exposure by its distinctive light-gray- or yellow-weathering color.

The thickness of the Niobrara ranges from about 700 to 730 feet in the various drill holes throughout the area and may reach as much as 800 feet in the westernmost exposures. In the Tow Creek area, about 25 miles to the west, the Niobrara is about 1,100 feet thick, and continues to thicken farther west (Bass and others, 1955, p. 151).

The Fort Hays Limestone Member is nearly everywhere poorly exposed. In drill holes it ranges from 15 to 23 feet in thickness and appears to be about the same in surface exposures. It consists of poorly bedded gray to brownish-gray light-gray-weathering finely granular limestone and probably of thin beds of dark-gray calcareous shale. The nature of the basal contact with the Codell Sandstone Member of the Benton Shale is not known, but in northwestern North Park the contact is sharp, and may be disconformable.

The Smoky Hill Shale Member consists of calcareous shale and shaly limestone. It ranges in thickness from about 685 to 710 feet in drill holes. The lower one-third of the Smoky Hill is predominantly dark-gray calcareous shale which weathers to dark gray or brown, but is locally light gray. Bedding is thin to fissile but inconspicuous. The upper two-thirds is interbedded dark calcareous shale and thin shaly limestone. Fissile, papery bedding is conspicuous in much of the shale. Most beds in the upper part are dark gray or brown but tend to weather readily to very light gray or light yellow. Many of the upper beds are speckled with shells or fragments of foraminifera or other microfossils. Fragments of *Inoceramus* are abundant on many weathered slopes. The contact of the Smoky Hill with the underlying Fort Hays is probably conformable.

298-047 O—68——6

The upper boundary of the Niobrara is difficult to place with certainty inasmuch as it lies in a transitional sequence, as much as 100 feet thick, between brittle platy yellow-weathering calcareous shale typical of the upper part of the Smoky Hill Member and soft dark-weathering noncalcareous shale typical of the lower part of the Pierre.

The Niobrara is correlated on the basis of lithology and stratigraphic position with the Niobrara of eastern Colorado and southern Wyoming. In western Colorado, Niobrara equivalents are readily recognized within the Mancos Shale. A small fossil collection from the Fort Hays in the block slide in the NE¼ sec. 3, T. 3 N., R. 82 W. (USGS Mesozoic loc. D3669, pl. 3, fossil loc. 4) includes *Inoceramus* n. sp. and *Ostrea* sp. These were identified by W. A. Cobban who said "The *Inoceramus* marks the oldest faunal zone known in the Fort Hays."

PIERRE SHALE

The Pierre Shale of Late Cretaceous age is the uppermost Cretaceous formation in the area, and only a part of the Pierre is present. Pre-Tertiary erosion removed the upper beds of the Pierre and presumably higher Cretaceous formations. The Pierre conformably overlies the Niobrara Formation and unconformably underlies Tertiary rocks of the Coalmont Formation. The Pierre in the mapped area consists almost entirely of marine shale, sandstone, and siltstone—a very thin nonmarine sequence may be present. The formation is divided into two members for mapping purposes. The lower is designated the shaly member; the upper is designated the sandy member. This usage follows that in northwestern North Park. The contact between the two members is not well defined but generally divides the predominantly shale lithology of the lower part from the predominantly sandstone lithology of the upper part.

The Pierre is mostly nonresistant and easily eroded, particularly the shaly member, and commonly forms lowlands or gentle slopes. The sandy member is relatively more resistant than the shaly member and in the southeastern part of the area forms a poorly defined area of high ground above the shaly member. The soft nonresistant nature of the Pierre has permitted the development on its surface of very abundant landslides and colluvial material, and the formation for the most part is very poorly exposed.

The thickness of the Pierre Shale in the mapped area is not well known owing to poor exposure and considerable surficial cover in the outcrop area of the sandy member. Erosion stripped away all or part of the Pierre prior to the deposition of Tertiary rocks, so that nowhere in the area is the Pierre preserved in its original thickness. The maximum preserved thickness of the Pierre may be as much as 5,000 feet in the southern part of the area. The shaly member is thickest in the southern part of the area, and ranges from 1,400 to 2,400 feet in thickness. Measurements from north to south indicate that it is about 1,400 feet thick in the Hiawatha test hole, 1,700 feet thick in the Buffalo Creek test hole, at least 2,080 feet thick in the Pony Creek test hole, 2,000 feet thick in the outcrop band between Grizzly Creek and Whiteley Peak, 2,150 feet thick near the Walters test hole, and attains its maximum thickness of about 2,400 feet a little farther south near the DeBerard test hole. Structural complexities may account for some of the apparently increased thickness in the south. The thickness of the sandy member is determined by the extent of post-Cretaceous erosion. It reaches its apparent maximum thickness in the southeastern part of the area, but an accurate thickness cannot be measured owing to a cover of surficial material. The sandy member may be as much as 3,000 feet thick in this area.

The shaly member consists mostly of dark-gray marine shale. Its basal beds are transitional from the Niobrara Formation through a thickness of as much as 100 feet and are calcareous. Many beds included in the Pierre contain specks of microfossils typical of the Niobrara, but the Pierre weathers gray rather than yellow, and the contact is placed at the position of maximum color change. Locally, as in the southeast corner of the Lake Agnes quadrangle, the transition zone of the Niobrara and Pierre contains rusty-weathering calcareous speckled shale, and the contact is placed at the top of the highest conspicuous rusty shale bed. The lower part of the shaly member, above the basal calcareous shale, is soft very dark gray noncalcareous shale containing sparse very thin rusty-weathering siltstone laminae and sparse thin lenticular calcareous sandstone beds. Higher in the shaly member, rusty siltstone laminae are more conspicuous, and the beds contain sparse concretionary claystone or siltstone masses, some of which are calcareous. The concretionary masses range from a few inches to a foot or two in diameter. These, even though not abundant, are more numerous higher in the section. They apparently do not reach the large size—as much as 8 feet long—attained by similar concretions in the northern part of northwestern North Park. The upper part of the shaly member becomes increasingly silty and sandy toward the top, and the color of the weathered shale becomes somewhat lighter.

The sandy member of the Pierre consists of interbedded marine sandstone, shale, sandy shale, and siltstone. The sandy member lies conformably on the shaly member, and the contact with the shaly member is generally placed at the base of the lowest conspicuous sandstone in a transitional sequence. In the area between the north end of its outcrop and a point about a mile north of the Haworth Ranch, the contact is drawn on the base of a sandstone bed containing a brown to rusty-weathering clay-pebble conglomeratic sandstone. This unit forms a persistent ridge in the vicinity of Diamond Creek, but farther south it is nonresistant and crops out intermittently. In the area from Lindsay Creek to the vicinity of Indian Pass, the contact is drawn on the base of the lowest ridge- or ledge-forming sandstone. From Indian Pass to the south boundary of the area, resistant sandstone beds are absent and the contact is drawn at the base of a fairly thick sequence of nonresistant sandstone.

The lower part of the sandy member consists of even-bedded cross-laminated nonresistant sandstone or siltstone interbedded with fissile to blocky-weathering silty shale or claystone. The more resistant sandstone beds are calcareous. Septarian concretions like those in the shaly member are present in many of the shaly beds. The middle part of the sandy member is very poorly exposed and little is known of its lithology, but it is probably similar to the lower part. Sparse outcrops are mostly shaly sandstone. Exposures of the upper part of the sandy member include some resistant ridge-forming sandstone beds along Antelope Creek in the extreme southeast corner of the area. Bentonite beds occur in the sandy member, but their stratigraphic distribution is not known. At least one outcrop, in the SE¼ sec. 35, T. 4 N., R. 81 W., near the middle part of the sandy member contains thin beds of carbonaceous shale. This fact suggests possible nonmarine or marginal-marine deposition. A ridge-forming sandstone just east of Antelope Creek in the SW¼ sec. 29, T. 4 N., R. 80 W., in the upper part of the sandy member, contains *Ophiomorpha* and abundant bottom-dweller trail and burrow casts that suggest shallow marine or brackish-water deposition.

The Pierre Shale is correlated with the Pierre of eastern Colorado. The shaly member is approximately equivalent to that part of the Pierre below the Hygiene Sandstone Member of eastern Colorado, to the Steele Shale of Wyoming, and to that part of the Mancos Shale overlying the Niobrara equivalent of western Colorado. The sandy member is approximately equivalent to the Hygiene through Rocky Ridge Sandstone Members, and possibly higher beds, of eastern Colorado, to part of the Mesaverde Formation of southern Wyoming, and to the Iles and part of the Williams Fork Formations of western Colorado.

Several fossil collections were made from the Pierre in the area; a list of the fossils is given below. All fossils were identified by W. A.

Cobban, and remarks quoted below are by Cobban. Locality numbers listed are those shown on plates 1–3.

Fossil locality 5 (USGS Mesozoic loc. D3515), SW¼NW¼ sec. 20, T. 4 N., R. 81 W. Shaly member, about 1,000 ft above base. *Inoceramus* sp., *Baculites* sp., *Scaphites* n. sp. Remarks: "The baculites are smooth to noded in the juvenile stage and smooth in the adult stage. Baculites of this type characterize rocks equivalent to the Shannon Sandstone Member of Steele Shale of central Wyoming and the Groat Sandstone Bed of the Gammon Ferruginous Member of the Pierre Shale of the Black Hills Region."

Fossil locality 6 (USGS Mesozoic loc. D3890), SE¼NW¼ sec. 30, T. 4 N., R. 81 W. Shaly member, about 1,300 ft above base. *Inoceramus* sp., *Baculites* sp., *Scaphites* n. sp. Remarks: "The scaphite indicates a level just above the top of the zone of *Scaphites hippocrepis* and below the zone of *Baculites obtusus*."

Fossil locality 7 (USGS Mesozoic loc. D2641), E½NW¼ sec. 7, T. 5 N., R. 81 W. Shaly member about 1,500 ft above base. *Inoceramus* sp., *Lucina* sp., *Baculites asperiformis* Meek. Remarks: "The baculite marks a lower Pierre zone."

Fossil locality 8 (USGS Mesozoic loc. 4513), SW¼SE¼ sec. 17, T. 4 N., R. 81 W. Shaly member, about 1,800 ft above base. *Inoceramus* sp., *Cymbophora* sp., *Baculites* cf. *B. asperiformis* Meek. Remarks: "Probably zone of *B. asperiformis*."

Fossil locality 9 (USGS Mesozoic loc. 3516), NW¼NW¼ sec. 8, T. 4 N., R. 81 W. Sandy member, about 200 ft above base. *Inoceramus subcompressus* Meek and Hayden, *Baculites* sp. Remarks: "Suggests either zone of *Baculites perplexus* or zone of *B. gilberti*."

Fossil locality 10 (USGS Mesozoic loc. D4510), SE¼NW¼ sec. 17, T. 4 N., R. 81 W. Sandy member, about 260 ft above base *Inoceramus* sp., *Baculites perplexus* Cobban.

Fossil locality 11 (USGS Mesozoic loc. 4511), SW¼SE¼ sec. 17, T. 4 N., R. 81 W. Sandy member, basal bed. *Baculites* sp. (either *B. perplexus* or *B. gilberti*).

Fossil locality 12 (USGS Mesozoic loc. 4299), SE¼NW¼ sec. 35, T. 4 N., R. 81 W. Sandy member, about 650 ft above base, pyriporid bryozoan, *Baculites perplexus* Cobban.

Fossil locality 13 (USGS Mesozoic loc. 4302), NE¼SW¼ sec. 2, T. 3 N., R. 81 W. Sandy member, about 200 ft above base. pyriporid bryozoan, *Inoceramus* sp., *Baculites perplexus* Cobban.

Fossil locality 14 (USGS Meozoic loc. 3517), SE¼SW¼ sec. 32, T. 5 N., R. 81 W. Sandy member, about 260 ft above base. *Inoceramus sublaevis* Hall and Meek, *Pteria* cf. *P. linguaeformis* (Evans and Shumard), *Cymbophora holmesi* (Meek), *Anisomyon* cf. *A. borealis* (Morton), *Baculites* sp. Remarks: "As a guess I would say this assemblage is about the age of the Hygiene Sandstone Member of the Pierre Shale of the Front Range."

Fossil locality 15 (USGS Mesozoic loc. 4509), SE¼NW¼ sec. 17, T. 4 N., R. 81 W. Sandy member, about 320 ft above base. *Inoceramus* aff. *proximus* Tuomey, *Baculites gregoryensis* Cobban.

Fossil locality 16 (USGS Mesozoic loc. D3518), NE¼SW¼ sec. 10, T. 4 N., R. 81 W. Sandy member, about 1,700 ft above base. *Inoceramus tenuilineatus* Hall and Meek, *Baculites* sp., *Didymoceras* cf. *D. stevensoni* (Whitfield), *Oxybeloceras* sp. Remarks: "Probably zone of *Didymoceras stevensoni*."

Fossil locality 17 (USGS Mesozoic loc. D4300), SE¼NW¼ sec. 1, T. 3 N., R. 81 W. Sandy member, about 2,000 ft above base. *Inoceramus pertenuis* Meek and

Hayden, *Pteria* cf. *P. linguaeformis*, *Baculites crickmayi* Williams, *Didymoceras stevensoni* (Whitfield), *Oxybeloceras crassum* (Whitfield). Remarks: "Zone of *Didymoceras stevensoni*."

Fossil locality 18 (USGS Mesozoic loc. D4301), NE¼SW¼ sec. 32, T. 4 N., R. 80 W. Sandy member; stratigraphic position not known, but estimated at about 2,700 ft above base. *Inoceramus* cf. *I. vanuxemi* Meek and Haydin, *Lucina subundata* Hall and Meek, *Baculites compressus* Say, *Hoploscaphites* sp.

The contact between the shaly and sandy members falls within or below the zone of *Baculites perplexus* and above the zone of *Baculites asperformis*.

TERTIARY SYSTEM

PALEOCENE AND EOCENE SERIES

COALMONT FORMATION

The Coalmont Formation was named by Beekly (1915, p. 50) in his reconnaissance study of North Park:

> * * * all the strata which rest unconformably upon the marine Cretaceous and are overlain by the North Park (Tertiary formation * * * are here treated as a single formation to which the name Coalmont is applied. The formation is much better exposed along North Platte River than in the vicinity of Coalmont * * * but the name Coalmont is used as the most acceptable name not preoccupied or otherwise unsuitable.

Beekly did not measure a section of the formation in the Coalmont area. His definition is mainly followed in this report, and the Coalmont here includes all nonmarine strata unconformably overlying the Pierre Shale of Late Cretaceous age, or older formations, and unconformably underlying various Tertiary units of Oligocene or younger age. The age of the Coalmont is Paleocene and Eocene.

Marvine (1874, p. 156–157) first described the beds here included in the Coalmont Formation in northwestern Middle Park. He termed the beds the "lignitic formation." The name Middle Park as applied to these beds was used informally as far back as 1879 in reports of the Hayden Survey (White, 1879, p. 203). Later geologists—for example, Emmons (1890, p. 281), Clark (1891, p. 137), and Cross (1892, p. 29)—continued to use Middle Park as a geologic name, and the name has since become firmly established in Middle Park.

In the area of this report, the Middle Park is considered to be of member rank, and the Coalmont is locally divided into three members: the Middle Park Member, a middle member, and an upper member. In the Coalmont-Pole Mountain area, the middle and upper members are separated by an unconformity marked by an abrupt change from sandstone and conglomerate below to carbonaceous shale above (fig. 4). This contact is mapped as far as possible but, in much of the area, clear evidence for unconformity is lacking, and the eastward extent of the unconformity is unknown owing to lack of subsurface information. In the northeastern part of the Spicer Peak quadrangle, east of Grizzly Creek, Arapaho Ditch, and Arapaho Creek, the Coalmont is not differentiated, but probably consists mostly of the upper member.

The Coalmont is largely nonresistant and easily eroded, and forms lowlands, flatlands, or slopes. Locally, moderately well cemented sandstone or conglomerate beds, particularly in the Middle Park Member and middle member, form cliffs, weak ridges, or hogbacks, as in the area north of Chedsey Creek in the extreme northern part of the area, in the Mexican Ridge area, and on Grannys Nightcap. The Coalmont is more resistant than the underlying Pierre Shale and its basal beds form a poorly defined line of high ground above the Pierre in the west-central part of the area. Where the Coalmont underlies prominent hills, such as Pole Mountain, Mexican Ridge, and Spicer Peak, these hills are capped by volcanic rock, or heavy rubble of volcanic rock which gives protection from erosion. Much of the area underlain by the Coalmont is commonly obscured by a cover of surficial material.

The thickness of the Coalmont is difficult to estimate because of large areas of poor exposure, structural complexities, and the lack of information on the irregularities of the pre-Coalmont surface. The thickest known (1,320 ft) partial section of the upper member was

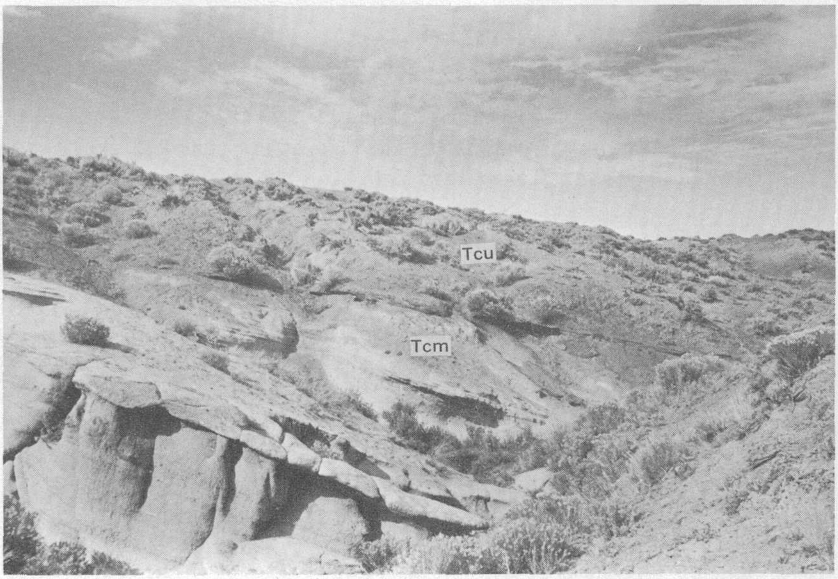

FIGURE 4.—Locally unconformable contact between coarse arkosic sandstone of the middle member of the Coalmont Formation (Tcm) and dark-brown carbonaceous shale of the upper member (Tcu). SE¼ sec. 9, T. 7 N., R. 81 W., just north of Chedsey Creek.

penetrated in the Hiawatha test hole, a mile or so south of Coalmont. Estimates from outcrops indicate that the upper member may be as much as 5,500 feet thick within the northeastern part of the area, on the assumption that it was deposited on an even sub-Coalmont surface. All other drill holes penetrated lesser partial thicknesses of the upper member; these range from about 700 to 1,250 feet. The middle member ranges from 1,765 to 2,740 feet in thickness in drill holes that penetrated the entire unit. This member is thickest, 2,740 feet, in the Buffalo Creek test hole and thinnest, 1,765 feet, in the Hiawatha test hole. It may be as little as 1,000 feet thick in some outcrops. Estimates from outcrops across 5 miles in the extreme north-central part of the area indicate that the middle member may aggregate as much as 6,000 feet in thickness, but nothing is known about the actual depth to the base of the Coalmont. Sub-Coalmont buried hills could substantially alter these estimates.

The Middle Park Member has a maximum thickness of about 600 feet, and it thins to zero where overlapped by the middle member of the Coalmont Formation. Much of the thinning of the Middle Park Member is due to the lack of basal beds on an irregular surface cut into the Pierre Shale. Locally, as near Diamond Creek and Grannys Nightcap, the basal contact rises in the direction of the northeastward regional dip.

The Coalmont consists of a heterogeneous mixture of nonmarine sandstone, conglomerate, claystone or mudstone, carbonaceous shale, and coal. These rocks are probably flood-plain, alluvial, and swamp deposits. The coarse detrital constituents are mostly arkosic, consisting of quartz, feldspar, and dark minerals, and a small amount of fragmental rock. Waterworn volcanic rock pebbles are present in the Middle Park Member and were derived from a source to the southeast. The arkosic constituents were undoubtedly derived from surrounding highlands of Precambrian crystalline rock. The abundant clay making up the claystone and mudstone may have been derived in part from Cretaceous shale, or from decomposition of detrital feldspars.

Middle Park Member

The differentiation of the Middle Park Member is made on the basis of its content of volcanic-pebble beds which characterize the Middle Park Formation to the southeast of the mapped area. The Middle Park Member consists of arkosic sandstone and conglomeratic sandstone, volcanic-pebble conglomerate, sandy claystone or mudstone, and sparse carbonaceous shale. The coarser arkosic beds contain angular fragments of quartz, feldspar, and other minerals, presumably derived from surrounding highlands of Precambrian crystalline rock. The volcanic fragments in the conglomeratic beds are mostly medium- to light-gray-weathering porphyritic andesites or similar rock types, and range from pebble size (2 in.) to sand size. Some pebbly beds are entirely arkosic, others are entirely volcanic, and mixtures of the two types occur in all proportions. The volcanic constituents were probably derived from sources to the southeast and may represent tongues or channels in the otherwise predominantly arkosic sequence. The conglomeratic beds are generally the most resistant and form the steep scarps of Grannys Nightcap, but elsewhere conglomeratic beds are nonresistant and form slopes. The sandstones are mostly arkosic but many contain volcanic grit or sand. Micaceous beds are abundant. The sandstone beds grade into, or are interbedded with, nonresistant sandy claystone. Thin carbonaceous shale beds are present locally. The conglomerate and sandstone beds are mostly grayish brown, and the claystone beds are various shades of brown, greenish gray, and light gray.

The contact between the Middle Park Member and the middle member is drawn at the top of the highest occurrence of gravelly beds that contain waterworn pebbles of porphyritic andesite or similar volcanic rock. Except for the content of volcanic rock pebbles in the Middle Park Member, the lithologies of higher beds in the Coalmont and beds in the Middle Park Member are quite similar.

The criterion of drawing the contact at the top of the volcanic-pebble beds appears to be useful, at least locally in field mapping. The units containing the volcanic pebbles probably represent tongues or channel deposits of material derived from a source southeast of this area. These tongues lie within an otherwise predominantly arkosic sequence typical of both the Coalmont and Middle Park. Thus the Middle Park Member, as mapped in this area, represents a stratigraphically low tongue of volcanic-pebble conglomerate including underlying and intercalated arkosic material. Higher beds, lacking tongues of volcanic pebbles, are assigned to the middle or upper members of the Coalmont Formation.

Middle member

The middle member consists of crossbedded arkosic sandstone and conglomeratic sandstone and gray or green sandy claystone or mudstone; carbonaceous shale and coal are sparse. In this area the sandstone and conglomerate beds are moderately resistant where cemented by calcite and form low ridges or hogbacks; clayey beds are nonresistant.

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Throughout most of the area, north of Diamond Mountain, the middle member of the Coalmont is in contact with the Pierre Shale. This contact is rarely well exposed. In an exposure just north of the mouth of Doran Creek, the basal beds of the Coalmont are coarse unsorted cobble conglomerates. The largest cobbles are about 10 inches long and are thus considerably larger than most gravel clasts in higher beds of the Coalmont. The gravel is almost entirely Precambrian granitic rock, but also contains some fragments of resistant sandstone derived from the Dakota Sandstone.

In the outcrop area roughly between Chedsey Creek and the Middle Fork of Mexican Creek, the middle member consists of three distinct parts: a lower unit, about 630 feet thick, consisting of interbedded gray to brown conglomerate and sandstone and olive-green sandy claystone or mudstone; a middle unit, about 370 feet thick, consisting of gray to brownish-gray silty micaceous shale; and an upper unit, about 435 feet thick, consisting of interbedded brown to gray sandstone, conglomeratic sandstone, conglomerate, and brown, olive-green, or gray sandy claystone or mudstone. These three units may be recognized in drill holes to the east as far as the Buffalo Creek test hole, where additional units of coarsely sandy or conglomeratic beds and claystone appear below the lower unit. The lower unit thickens to as much as 1,130 feet in the Hendershot 1 test hole and to as much as 940 feet in the Buffalo Creek test hole. The upper unit, however, is markedly thinner in the drill holes, having a minimum thickness of 190 feet in the Lockhart Government 1 test hole. Thinning of the upper part in this area is probably due to erosion below the unconformity separating the middle member from the upper member of the Coalmont.

South of Mexican Creek the middle shale unit of the middle member apparently pinches out and the entire middle member consists of sandstone, conglomerate, and claystone typical of the upper and lower units. A few ridge-making sandstones are present in this area. Farther south, the middle member as a whole becomes less resistant and in general is poorly exposed. Apparently the proportion of sandstone beds increases, but the member does not contain the abundant gravelly beds that it does farther north. In the outcrop area south and east of Colorado and Grizzly Creeks, the middle member is mostly poorly exposed. Sparse outcrops or surface wash are generally soft rusty brown arkosic sand. Presumably, claystone or mudstone beds are abundant but are not commonly exposed. Carbonaceous shale and thin coal beds occur locally, as in the area just north of Grannys Nightcap.

Of special interest is the long narrow arm of Coalmont extending westward in the west-central part of the Rabbit Ears Peak quadrangle and overlapping all the older sedimentary rocks. The Coalmont in this area contains boulder conglomerates that interfinger with more typical Coalmont sandstone and conglomerate; the boulder beds thicken and the boulders become larger westward. In the vicinity of Rabbit Ears Peak and west beyond the quadrangle boundary, the unit contains large granitic boulders as much as 6 feet in length. The conglomerates are composed of Precambrian granitic rocks, obviously derived from a nearby source. The unit closely resembles an ancient glacial till. Bedding and sorting are virtually absent; many boulders are completely weathered and disintegrated.

Upper member

The upper member of the Coalmont consists of interbedded sandstone, claystone and mudstone, carbonaceous shale, and coal. Conglomeratic beds are present but are not abundant. The sandstone beds are fine to coarse grained, gray to light brownish gray, and mostly soft and nonresistant but locally contain resistant slabs and ledges. They are massive to crossbedded and locally even bedded, are arkosic, and generally contain much white mica. The claystone and mudstone beds are olive green and gray and are nonresistant. The carbonaceous shale is chocolate brown, silty and fissile to blocky and locally contains abundant ironstone nodules. Coaly beds occur in the lower to middle part of the upper member in the Coalmont-Pole Mountain area. (See discussion of economic geology.) Coal and coaly shale beds from 75 to 80 feet thick (Erdmann, 1941, p. 66) are present in the Coalmont district near the community of Coalmont.

The basal part of the upper member is brown carbonaceous shale. In the Pole Mountain-Coalmont area the contact with the middle member is sharp and unconformable (fig. 4). Probable unconformable relationships are also seen near the mouth of Indian Creek, but elsewhere unconformity is uncertain. The contact does, however, generally mark a change from arkosic clastic rocks of the middle member to carbonaceous shale of the upper member. The lower carbonaceous shale is about 775 feet thick southwest of Pole Mountain in sec. 4, T. 6 N., R. 81 W.; about 1,000 feet thick along the north bank of Chedsey Creek; about 770 feet thick in the Hiawatha test hole; and 660 feet thick in the Buffalo Creek test hole. Micaceous sandstone beds interlayered with carbonaceous shale, coal, and coaly shale overlie the basal carbonaceous shale, and most of the important coal beds occur in this part of the section through an interval of about 800 feet. Higher beds of the upper member are arkosic sandstone, claystone and mudstone, and sparse carbonaceous shale.

Correlation and paleontology

The Coalmont is correlated at least in part with the Middle Park Formation of Middle Park. On the basis of dating by fossil pollen, the Coalmont is Paleocene and Eocene in age, and probably correlates in part with both the Fort Union and Wasatch Formations of northwestern Colorado. On the basis of fossil leaves, the Coalmont correlates in part with the Denver Formation of eastern Colorado. The Middle Park Member is assigned to the Paleocene, although its age in this area is not definitely known; the middle member is Paleocene and Eocene; the upper member is Eocene.

The Coalmont, particularly the upper member, has yielded abundant fossil pollen and spores. These have been studied and classified by Estella B. Leopold and Helen Pakiser. Their findings appeared, in part, in two previous reports (Hail and Leopold, 1960, and Hail, 1965, p. 70–72). In summary, Leopold and Pakiser divide the Coalmont into three zones: pollen zone 1 is Paleocene in age; zones 2 and 3 are Eocene, probably early Eocene in age. Zone 1 contains pollen common to both Paleocene and Eocene, but contains no forms restricted to Eocene or younger rocks. Zones 2 and 3 contain pollen forms not known in rocks older than Eocene, and the two zones are differentiated on the basis of the proportion of these forms. Criteria for these zones include, in part, the following:

1. Pollen zone 1 (Paleocene): *Carya* (hickory) pollen is dominant (as much as 54 percent) in lower samples and is partly replaced by *Zelkova* (Asiatic elm) in upper samples; no Eocene and younger forms present.
2. Pollen zone 2 (Eocene): Several Eocene and younger forms appear in small numbers; *Platycarya* cf. *P. strobilaceae*, *Tilia*, and *Eucommia*. *Platycarya* increases in frequency within this zone, ranging from 5 to 10 percent of the pollen count in the basal samples to 16 percent at the top.
3. Pollen zone 3 (Eocene): All Eocene and younger forms are more common. *Platycarya* cf. *P. strobilacea* rises from a frequency of 27 percent in the basal sample to 40 percent in the higher samples. *Eucommia* is 5–7 percent of the count, and *Tilia* is 1–2 percent.

Fossil collections from four localities are assigned to zone 1 (Paleocene); all are from the middle member of the Coalmont in the northern part of the area. These are fossil localities 19–22:

Locality 19 (USGS paleobotanical loc. D1357), SW¼ sec. 13, T. 7 N., R. 82 W., upper part of the middle shale unit of the middle member, about 900 ft above the base of the Coalmont.

Locality 20 (USGS paleobotanical loc. D1411), NE¼ sec. 36, T. 7 N., R. 82 W., upper part of middle shale unit of the middle member, about 1,000 ft above the base of the Coalmont.

Locality 21 (USGS paleobotanical loc. D1410), NW¼ sec. 31, T. 7 N., R. 81 W., upper part of the middle shale unit of the middle member, about 1,150 ft above the base of the Coalmont. These samples contain *Carya* or *Zelkova;* Eocene and younger forms are absent.

Locality 22 (USGS paleobotanical loc. D1835), NE¼ sec. 3, T. 5 N., R. 82 W., probably within 100 ft above the base of the middle member. Leopold states: "In this sample *Carya* pollen (*Caryapollenites*) represents more than 40 percent of the assemblage."

Fossil collections from one locality are assigned to zone 2 (Eocene):

Locality 33 (USGS paleobotanical loc. D1408), W½ sec. 4, T. 6 N., R. 81 W., includes four collections ranging from 60 to 340 ft above the base of the upper member of the Coalmont.

Fossil collections from 11 localities are assigned to zone 3 (Eocene):

Fossil locality 24 (USGS paleobotanical loc. D1584), NE¼ sec. 3, T. 7 N., R. 81 W., about 100 ft above the base of the upper member of the Coalmont.

Fossil locality 25 (USGS paleobotanical loc. D1586), SE¼ sec. 9, T. 7 N., R. 81 W., includes two collections ranging from about 50 to 90 ft above the base of the upper member of the Coalmont.

Fossil locality 26 (USGS paleobotanical loc. D1587), SW¼ sec. 10, T. 7 N., R. 81 W., includes two collections ranging from about 240 to 280 ft above the base of the upper member of the Coalmont.

Fossil locality 27 (USGS paleobotanical loc. D1588), SW¼ sec. 10, T. 7 N., R. 81 W., about 330 ft above the base of the upper member of the Coalmont.

Fossil locality 28 (USGS paleobotanical loc. D1589), SW¼ sec. 10, T. 7 N., R. 81 W., includes two collections ranging from about 400 to 440 ft above the base of the upper member of the Coalmont.

Fossil locality 29 (USGS paleobotanical loc. D1590), NE¼ sec. 15, T. 7 N., R. 81 W., about 770 ft above the base of the upper member of the Coalmont.

Fossil locality 30 (USGS paleobotanical loc. D1591), NW¼ sec. 14, T. 7 N., R. 81 W., about 890 ft above the base of the upper member of the Coalmont.

Fossil locality 31 (USGS paleobotanical loc. D1592), NW¼ sec. 14, T. 7 N., R. 81 W., about 940 ft above the base of the middle member of the Coalmont.

Fossil locality 32 (USGS paleobotanical loc. D1593) SW¼ sec. 11, T. 7 N., R. 81 W., about 1,150 ft above the base of the middle member of the Coalmont.

Fossil locality 34 (USGS paleobotanical loc. D1409) NW¼ sec. 4, T. 6 N., R. 81 W., includes six collections ranging from about 450 to 770 ft above the base of the middle member of the Coalmont.

Fossil locality 35 (USGS paleobotanical loc. D1834), SW¼ sec. 14, T. 6 N., R. 81 W., stratigraphic position not known, but it is probably at least 1,000 ft above the base of the upper member of the Coalmont.

Fossil collections from three localities are Eocene but not clearly assignable to either zones 2 or 3:

Fossil locality 36 (USGS paleobotanical loc. D1892), SE¼ sec. 17, T. 6 N., R. 80 W., estimated about 1,750 ft above the base of the upper member of the Coalmont. The following pollen were identified: cf. *Picea*, *Araucariacites australis*, *Platycarya*, *Pteris*, *Alnus*, cf. *Eucommia*, and dinoflagellate algae. Leopold pointed out that the *Araucariacites* and the algae are particularly worn and that they are typical of a Cretaceous assemblage and may be reworked out of the Pierre Shale.

Fossil locality 37 (USGS paleobotanical loc. D1833) NE¼ sec. 2, T. 5 N., R. 81 W., about 100 ft above the base of the upper member. Leopold commented: "Abundant remains of *Azolla* (an aquatic fern) indicate a lacustrine environment. *Platycarya* pollen is the main basis for suggesting an Eocene age."

Fossil locality 38 (USGS paleobotanical loc. D1980), SE¼ sec. 35, T. 5 N., R. 81 W., lower part of the equivalent of the middle member of the Coalmont. The following pollen and algae were identified: *Carya* (dominant), *Botryococcus* (common), *Platycarya, Ulmaceae,* cf. *Ulmus,* cf. *Eucommia,* cf. *Engelhardtia.*

Fossil locality 39 (USGS paleobotanical loc. D1979), NE¼ sec. 3, T. 4 N., R. 81 W., lower part of the equivalent of the middle member of the Coalmont. Leopold commented: "Pollen is very rare and badly weathered. Only *Carya* and cf. *Platycarya* could be recognized."

A collection of fossil fresh-water snails was taken at fossil locality 23 (USGS Cenozoic loc. 23249) from the upper member, about 400–500 feet above the base, in the SE¼ sec. 35, T. 6 N., R. 81 W. These were examined by Dwight W. Taylor, who identified the snails as *Bellamya* and *Lioplacoides* or *Campeloma*, and he made the following comment:

The fossils are so poorly preserved that even a generic reference is possible only by knowing the fauna of this part of the column. Judging by the ranges of the genera listed above in western Wyoming, the fossils are no younger than very early Eocene (early Wasatchian). No distinction is possible between Paleocene and earliest Eocene on the basis of this material.

Brown (1962, p. 25) tentatively regarded the entire Coalmont as Paleocene in age:

Tentatively I am regarding the entire Coalmont Formation as Paleocene age, but the discovery of some species of pollen in the upper part of the formation may, on further confirmation, indicate that part of the Coalmont is Eocene in age (Hail and Leopold, 1960).

At least three, and probably four, of Brown's Paleocene fossil-leaf localities, 6006, 6099, 6102, and 6440 (Brown, 1962, p. 32), occur in this area within strata dated as Eocene on the basis of fossil pollen.

The Middle Park Member immediately underlies Eocene (dated by fossil pollen) strata of the lower member of the Coalmont Formation at Grannys Nightcap. It is similar in lithology to the Middle Park Formation, in part, dated as Paleocene in nearby areas. Knowlton (1930, p. 5–6) examined fossil leaves from the Middle Park Formation and determined from them that the Middle Park is correlative in age with the Denver Formation. The Denver is considered to be Late Cretaceous and Paleocene in age. Brown (1962, p. 75) reexamined a fossil seed pod collected by T. D. A. Cockerell from sec. 9, T. 4 N., R. 81 W., and identified it as *Robinia wardi* (Knowlton) Brown, n. comb. He made the following statement:

Cockerell assumed that his specimen came from strata of Laramie age, * * * but as leaves of *Platanus raynoldsi* Newberry are on the same block and as the containing strata are similar to the Coalmont formation in North Park and the Middle Park formation in Middle Park, the age is Paleocene.

Middle Park and Coalmont relationship

The Middle Park Member of this area includes only the lower beds of Marvine's "lignitic formation" (1874, p. 180–181), to which the name Middle Park was later applied. Marvine's discussion leaves little doubt that his "lignitic formation" included beds here assigned to both Middle Park and higher members of the Coalmont and that it crosses the divide between Middle and North Parks in this area. Geologists after Marvine's time confined their studies of these strata to the Middle Park area. Little or no work was done in North Park until Beekly's reconnaissance study in 1911 (Beekly, 1915). Beekly included all Tertiary rocks below the Miocene North Park Formation in his Coalmont Formation, and apparently made no attempt to determine the relationship of the Coalmont to the Middle Park, although he (1915, p. 58) did make the following comment: "It is believed that they [Coalmont strata] are continuous southward and are present in at least the northern part of Middle Park, although no fossils and very little lithologic data in support of this are available." The name Coalmont has become well established in North Park, and the correlation of the Coalmont Formation with the Middle Park Formation has yet to be finally resolved. D. M. Kinney (work cited in U.S. Geol. Survey, 1964, p. A96), working along the east-central boundary of North and Middle Parks, mapped an unconformity in the Middle Park and Coalmont rocks and suggested that this may be a convenient horizon for subdividing the sequence. Kinney pointed out that porphyritic andesite pebbles are abundant below the unconformity in Middle Park, become less abundant northward, and are absent from northern North Park; the pebbles are sparse above the unconformity in Middle Park, and are absent from North Park. Izett (1968) includes all pre-Oligocene Tertiary beds shown in the Hot Sulphur Springs 15-minute quadrangle of northern Middle Park in the Middle Park Formation, and regards them as being Late Cretaceous (?) and Paleocene in age.

MIOCENE SERIES

NORTH PARK FORMATION

Two very small outcrops are here questionably referred to the North Park Formation of Miocene age. The North Park crops out extensively on Peterson Ridge, about 2 miles north of the report area, where it consists mostly of calcareous ashy sandstone, conglomeratic sandstone, and limestone. There it unconformably overlies the Coalmont and White River Formations.

The North Park caps the highest point of Mexican Ridge and is represented by sparse outcrops of light-gray locally conglomeratic limestone, which is not more than 80 feet thick. Pebbles in the limestone are of volcanic rocks typical of the North Park elsewhere, and of granitic rocks, which probably reflect the close proximity to the Park Range as a source area. The limestone is overlain by rubble of trachybasalt that is probably the remnant of a flow that originated in the vicinity of Rabbit Ears Peak.

The other outcrop of the North Park is in the southern part of the area, in sec. 31, T. 4 N., R. 81 W. The formation, probably not more than 30 feet thick, consists of nodular light-gray fine-grained sandstone or siltstone apparently interbedded with light-gray to tan volcanic ash or ashy siltstone. Float from this unit also includes calcareous volcanic pebble conglomerate. The North Park here lies near volcanic breccia, but the relationship to the breccia is obscure.

Scattered patches of rubble typical of North Park lithology are present at many places in the Mexican Ridge-Pole Mountain area. Most of these patches occupy high ground of hill tops or upper slopes, and some of them may represent true outliers of the North Park. More likely, however, they are residual remnants of a formerly widespread blanket of North Park strata.

In its type area, just north of this area, and in northern Jackson County, Colo., the North Park Formation is dated as late Miocene (Hail and Lewis, 1960; Hail, 1965, p. 84–85). Correlation of the scattered outcrops in the mapped area with the type North Park is made on the basis of similar lithology. In the Kremmling area to the south, Izett (1968) correlated the Troublesome Formation with the North Park Formation, and he designated the Troublesome as late early and late Miocene in age.

IGNEOUS ROCKS—TERTIARY

Tertiary igneous rocks are scattered throughout the area except in the Coalmont quadrangle, but their aggregate area of exposure is small. (See table 2.) The largest single outcrop area occupies about 5 square miles in the Whiteley Peak quadrangle. The Tertiary igneous rocks occur as shallow dikes, sills, and plugs and as flows, volcanic breccia, and ash. Because they are resistant relative to the surrounding sedimentary rocks, most of the igneous rocks are topographically prominent and form many of the hills in the area.

TABLE 2.—*Sample localities of Tertiary igneous rocks, the analyses of which are shown in tables 3 and 4*

[All rock names are according to Rittmann classification (1952, p. 75-102, pls. 1-7)]

Sample	Laboratory No.	Quadrangle	Locality Sec.	T.(N.)	R.(W.)	Remarks
			Map unit: rhyolite (Tir)			
1	159888	Lake Agnes	NW¼ 6	4	81	
2	159884	Whiteley Peak	NW¼ 9	4	81	
3	158147	do	NE¼ 25	5	81	
4 [1]	158146	Spicer Peak	SW¼ 21	5	80	
5	159893	Lake Agnes	SE¼ 26	5	82	Dark rhyolite.
			Map unit: rhyolitic flow breccia (Trb)			
6 [1]	159881	Whiteley Peak	SE¼ 31	5	80	Rhyolite.
			Map unit: quartz latite (Tql)			
7	162469	Whiteley Peak	SE¼ 23	4	81	
8	162466	do	SW¼ 8	4	81	Dark quartz latite.
9	159885	do	SE¼ 8	4	81	Rhyodacite.
10	159886	do	NW¼ 17	4	81	Dark quartz latite.
			Map unit: rhyodacite (Tird, Trrd)			
11	158139	Rabbit Ears Peak	SE¼ 23	5	82	
12	158131	do	NE¼ 20	5	82	
13	158136	do	NE¼ 22	5	82	Dark rhyodacite.
14	159890	Lake Agnes	NE¼ 30	5	81	
15	159894	do	SW¼ 26	5	82	Dark rhyodacite.
16	158141	do	NE¼ 30	5	81	Do.
			Map unit: rhyodacitic volcanic ash (Tra)			
17	158130	Rabbit Ears Peak	NW¼ 4	5	82	Labradorite rhyodacite.
			Map unit: trachyte (Tt)			
18	158135	Lake Agnes	SE¼ 21	5	82	Dark rhyodacite.
19	158134	Rabbit Ears Peak	SE¼ 21	5	82	Olivine trachyte.
20	159887	Lake Agnes	SE¼ 21	5	82	Olivine latite.
21	159889	do	NE¼ 7	4	81	Olivine trachyte.
			Map unit: latite (Tl, Trl)			
22 [1]	159883	Whiteley Peak	NW¼ 28	5	80	Light latite.
23 [1]	162460	Spicer Peak	NE¼ 18	5	80	
24	162468	Whiteley Peak	SE¼ 4	3	81	
25	158129	Teal Lake	NE¼ 2	6	82	
26	159895	Lake Agnes	NE¼ 4	4	82	Olivine latite.

See footnote at end of table.

TABLE 2.—*Sample localities of Tertiary igneous rocks, the analyses of which are shown in tables 3 and 4*—Continued

Sample	Laboratory No.	Quadrangle	Locality Sec.	T.(N.)	R.(W.)	Remarks
			Map unit: trachyandesite (Tta, Trta)			
27 [1]	162464	Whiteley Peak	SW¼ 6	4	80	Light trachyandesite.
28 [1]	162458	Spicer Peak	SW¼ 19	5	80	
29	159892	Lake Agnes	SE¼ 36	5	82	
30	162454	Rabbit Ears Peak	NW¼ 19	5	81	
31	159882	Whiteley Peak	SW¼ 8	4	80	
32	159891	Lake Agnes	SE¼ 30	5	81	
33 [1]	159880	Whiteley Peak	SW¼ 6	4	80	
34	162456	Rabbit Ears Peak	NE¼ 20	5	81	
35	158142	Lake Agnes	NE¼ 30	5	81	
36	162465	do	SE¼ 30	4	81	Olivine trachyandesite.
37	162453	Rabbit Ears Peak	NW¼ 23	6	82	Do.
38	162455	do	NE¼ 27	6	82	Labradorite andesite.
			Map unit: trachybasalt (Ttb, Tytb)			
39	158143	Rabbit Ears Peak	NW¼ 4	5	82	Trachyandesite.
40	162467	Whiteley Peak	SW¼ 5	3	81	Andesine trachybasalt.
41	158137	Rabbit Ears Peak	SW¼ 35	6	82	Andesine basalt.
42	162463	do	NW¼ 4	4	82	Olivine andesine trachybasalt.
43	158140	Lake Agnes	NW¼ 25	5	82	Do.
44	162457	Spicer Peak	SW¼ 33	6	81	Olivine andesine trachybasalt (float).
45	162461	Rabbit Ears Peak	NE¼ 5	5	82	Olivine andesine trachybasalt.
46	162462	do	NE¼ 5	5	82	Do.
47	158133	do	NW¼ 4	5	82	Do.
48	159879	Whiteley Peak	NW¼ 7	4	80	Do.
49	162452	Rabbit Ears Peak	NE¼ 6	5	81	Do.
50	158144	do	NW¼ 17	6	81	Olivine trachybasalt.
			Map unit: basanite (Tb)			
51	162459	Rabbit Ears Peak	NW¼ 20	5	81	Dark leucite basanite.

[1] Location approximate, township unsurveyed.

For purposes of mapping and discussion, extrusive rocks and intrusive rocks are treated separately, although it is likely that most of these rocks are part of a single igneous complex. The extrusive rocks probably once extended over a much greater area, perhaps entirely across the mapped area on the west and have been largely removed by post-Tertiary erosion. The present volcanic intrusive rocks now exposed in areas away from the Rabbit Ears Volcanics may have been sources for such volcanic material. Large masses of volcanic breccia rubble are present on hill tops and slopes in the southwestern part of T. 4 N., R. 81 W. These masses are now mapped as landslide deposits or colluvium but doubtless are let-down rubble of a once widespread deposit of volcanic breccia. In like manner, much rubble or scattered boulders of vesicular trachybasalt cap most of the hills in the northern part of the area, particularly on the crest and flanks of Mexican Ridge and Pole Mountain. These deposits are remnants of a once widespread flow or series of flows of trachybasalt, probably originating in part from the Rabbit Ears Peak volcanic center.

Previous work.—Tertiary igneous rocks of this area were mapped in reconnaissance by geologists of the Hayden and King surveys. Marvine (1874, p. 181) mapped all these Tertiary igneous rocks as basalt but in his brief description also mentioned thick volcanic conglomerate, tuff, and scoria. The Hayden atlas (1877) shows Marvine's mapping. Hague (in Hague and Emmons, 1877, p. 112–129) of the King survey described the rocks as trachytes and basalt. His trachytes included the rocks here included with the Rabbit Ears Volcanics. His basalts included all other Tertiary igneous rocks. King's volume on systematic geology (1878) incorporated Hague's work, and King's atlas (1876) shows outcrops of trachyte and basalt. Beekly (1915, p. 78–81, and pl. 12, geologic map) described such diverse rock types as andesite, basalt, volcanic agglomerate, augite minette, quartz latite, and latite porphyry, but he showed them all as basalt on his map. Grout and Worcester mapped the Tertiary rocks of this area, and Grout (in Grout and others, 1913, p. 44–55) in describing them in detail recognized four major rock types in addition to volcanic breccia: basalt, dacite porphyry, quartz latite, and andesite, which occur as dikes, laccoliths, plugs, and flows. Grout believed that all these rocks probably belong to a single, widely differentiated series (in Grout and others, 1913, p. 45–55); he based this conclusion on study in the field, microscopic study, and chemical analyses.

Classification.—The names applied to the Tertiary igneous rocks in the present report are based on a normative classification by Rittmann (1952, p. 95–102). A few of the map units contain a range of Rittmann rock types, and the units are classified according to the predominant rock. Tables 3 and 4 show chemical analyses, normative minerals, and Rittmann rock names of 51 samples. Table 2 shows sample localities and Rittmann rock names for these 51 samples.

All 51 samples for which normative CIPW calculations were made were also examined in thin section. Thin sections of 27 additional samples were examined. Hand samples of other rocks were classified by comparison to those classified on the basis of thin-section examination and chemical analysis.

TABLE 3.—*Chemical analyses (weight percent) of Tertiary igneous rocks*

[All rock names are according to Rittmann classification (1952, p. 75–102). Analyses in 1961, 1962 and 1964 by rapid rock analyses methods. Analysts: Paul Elmore, Ivan Barlow, Samuel Botts, Lowell Artis, and H. Smith]

	Map unit: rhyolite (Tir)						Map unit: rhyolitic flow breccia (Trb)	Map unit: quartz latite (Tql)				
Sample	1	2	3	4	5	Average	6	7	8	[1] 9	10	Average
SiO_2	75.2	74.6	72.3	71.3	54.8	69.6	73.9	65.2	61.3	60.9	60.4	62.3
Al_2O_3	13.7	14.0	14.2	15.0	11.9	13.7	12.7	17.7	15.4	16.2	15.3	16.1
Fe_2O_3	.71	.27	1.8	1.8	2.6	1.4	1.7	3.0	3.5	3.6	3.0	3.2
FeO	.02	.28	.06	.06	2.7	.6	.07	.20	1.4	1.6	2.0	1.2
MgO	.19	.10	.13	.31	4.6	1.1	.20	.36	3.0	2.7	3.7	2.4
CaO	.44	.53	.73	1.1	6.6	1.9	.93	2.5	4.4	3.9	4.4	3.8
Na_2O	3.9	4.4	4.0	4.1	2.6	3.8	3.7	4.3	4.0	4.4	4.2	4.2
K_2O	4.4	4.2	4.6	5.1	4.6	4.6	4.2	4.2	3.5	3.0	3.2	3.6
H_2O	1.3	1.2	1.8	.53	1.5	1.3	1.9	1.6	2.4	2.7	2.8	2.3
TiO_2	.03	.02	.34	.29	.91	.32	.31	.61	.72	.85	.82	.72
P_2O_5	.01	.01	.02	.11	.91	.21	.05	.23	.37	.36	.38	.33
MnO	.07	.09	.04	.09	.12	.08	.08	.07	.06	.08	.10	.08
CO_2	<.05	<.05	<.05	<.05	4.4	----------	<.05	<.05	<.05	<.05	<.05	----------
Total	100	100	100	100	98	----------	100	100	100	100	100	----------

	Map units: rhyodacite (Tird and Trrd)							Map unit: rhyodacitic volcanic ash (Tra)	Map unit: trachyte (Tt)				
Sample	11	12	13	14	15	16	Average	17	[1] 18	19	[2] 20	21	Average
SiO_2	60.9	60.7	59.5	55.5	55.0	54.4	57.67	65.1	58.3	56.6	54.8	53.2	54.9
Al_2O_3	15.8	16.1	14.8	16.3	14.9	15.9	15.63	13.1	14.7	14.2	14.1	13.8	14.0
Fe_2O_3	3.3	6.1	3.8	3.0	5.5	1.2	3.8	5.1	2.1	4.4	3.5	4.1	4.2
FeO	1.6	.44	1.6	2.8	1.9	4.4	2.1	.08	3.5	2.4	3.2	2.9	2.6
MgO	3.0	.55	4.3	2.1	2.4	2.9	2.5	1.6	3.8	3.7	5.6	6.6	5.1
CaO	4.3	2.6	4.5	4.5	3.9	4.5	4.0	2.1	5.5	4.7	5.5	5.7	5.2
Na_2O	4.3	4.0	4.0	3.7	3.6	3.6	3.9	1.8	3.9	3.3	3.2	3.2	3.2
K_2O	3.0	3.1	2.9	3.0	2.6	2.8	2.9	2.2	2.8	4.6	4.4	5.2	4.9
H_2O	2.2	4.6	3.2	2.9	5.5	1.9	3.4	8.2	.95	2.4	2.3	2.3	2.3
TiO_2	.76	1.1	.84	1.2	1.2	1.2	1.0	.45	.96	1.7	1.6	1.5	1.6
P_2O_5	.36	.43	.38	.48	.57	.47	.45	.13	.36	.80	.74	.94	.87
MnO	.08	.08	.08	.11	.10	.08	.09	.05	.10	.09	.11	.11	.10
CO_2	<.05	<.05	.17	4.7	3.0	6.0	----------	<.05	2.5	.07	.15	.15	----------
Total	100	100	100	100	100	99	----------	100	99	99	99	100	----------

	Map units: latite (Tl and Trl)						Map units: trachyandesite (Tta and Trta)											
Sample no	22	23	24	25	26	Average	27	28	29	30	31	32	33	34	35	36	37	[3] 38	Average
SiO_2	63.4	56.9	54.7	51.3	50.0	55.3	57.3	55.2	55.1	53.6	53.5	53.4	53.3	53.0	52.8	52.2	49.2	48.9	53.51
Al_2O_3	17.9	17.4	15.0	17.0	14.1	16.3	18.8	19.0	15.7	17.1	17.4	16.3	17.7	16.5	16.5	15.4	15.1	15.4	16.9
Fe_2O_3	3.5	5.9	5.1	6.5	2.5	4.7	6.4	6.3	1.8	5.8	6.1	2.8	6.0	5.3	4.0	4.9	6.0	5.1	5.0
FeO	.46	.60	2.7	1.7	6.7	2.4	.28	1.0	4.3	1.6	2.4	4.1	1.3	2.3	2.9	4.1	3.6	4.6	2.5
MgO	.46	1.6	4.5	2.5	9.1	3.6	.04	.71	2.8	3.2	2.6	4.2	.75	4.1	3.3	4.7	4.2	4.5	2.8
CaO	2.3	4.6	5.8	3.8	7.3	4.8	4.9	5.2	5.0	5.5	6.8	5.8	7.0	6.2	5.8	8.1	10.0	8.9	6.4
Na_2O	4.9	4.8	3.8	5.5	3.5	4.5	4.0	4.5	4.0	4.1	4.4	4.0	4.0	4.1	4.0	3.2	3.0	2.6	3.9
K_2O	4.6	4.5	3.8	3.6	2.9	3.9	3.4	3.7	2.6	3.2	2.8	2.7	3.0	3.1	3.2	2.0	1.8	1.3	2.9
H_2O	1.3	1.20	1.7	5.4	1.7	2.1	2.2	2.0	2.0	2.9	2.0	2.5	2.8	3.2	2.8	3.2	4.0	6.5	2.7
TiO_2	.68	1.4	1.6	1.4	1.6	1.3	1.8	1.6	1.2	1.5	.88	1.4	1.4	1.7	1.5	1.5	1.7	1.6	1.5
P_2O_5	.31	.55	.71	.96	.65	.64	.78	.61	.45	.59	.60	.48	.77	.47	.47	.48	.47	.47	.56
MnO	.13	.13	.13	.13	.17	.14	.03	.10	.10	.11	.20	.12	.11	.10	.09	.09	.16	.14	.11
CO_2	<.05	<.05	.05	.15	<.05	--------	<.05	<.05	5.3	<.05	.14	2.6	1.7	<.05	2.0	<.05	.86	<.05	--------
Total	100	100	100	100	100	--------	100	100	100	99	100	100	100	100	99	100	100	100	--------

	Map units: trachybasalt (Ttb and Tytb)													Map unit: basanite (Tb)
Sample no	[4] 39	40	[5] 41	42	43	44	45	46	47	48	49	50	Average	51
SiO_2	53.9	53.1	51.3	51.2	50.0	50.0	49.9	49.2	48.3	47.1	45.7	42.0	48.6	42.3
Al_2O_3	17.3	15.0	15.3	14.5	14.3	14.4	14.1	13.8	15.3	14.5	14.9	15.3	14.6	13.1
Fe_2O_3	8.3	4.4	2.7	7.1	3.6	6.6	6.0	7.4	12.9	6.1	4.2	4.7	6.3	5.1
FeO	.53	4.8	7.5	2.8	5.9	4.7	4.5	3.9	1.1	6.6	6.0	7.0	4.7	4.6
MgO	1.2	6.5	6.6	5.9	8.3	6.2	6.9	7.0	2.6	7.5	8.7	7.4	6.7	8.8
CaO	6.0	7.6	8.9	7.9	7.8	9.2	8.9	8.9	7.0	8.5	11.0	7.2	8.4	11.4
Na_2O	4.0	3.2	3.1	3.3	3.0	2.8	3.1	2.8	3.0	3.3	3.1	2.7	3.0	1.4
K_2O	2.2	1.9	1.3	2.3	2.1	1.7	2.3	2.1	2.0	1.7	1.5	2.2	2.0	2.7
H_2O	3.1	1.6	1.5	3.0	3.0	1.5	.92	2.4	4.1	2.0	.78	6.4	2.6	4.9
TiO_2	1.9	1.3	1.6	1.4	.73	1.7	1.6	1.6	1.8	2.2	2.5	2.9	1.8	2.2
P_2O_5	.60	.43	.42	.56	.64	.74	.47	.50	.60	.69	.66	.76	.60	.73
MnO	.17	.12	.14	.12	.14	.15	.17	.15	.08	.18	.13	.18	.14	.14
CO_2	<.05	<.05	<.05	<.05	<.05	<.05	1.1	.17	<.05	<.05	<.05	.06	----------	2.9
Total	99	100	100	100	100	100	100	100	99	100	99	99	----------	100

[1] Rhyodacite.
[2] Latite.
[3] Andesite.
[4] Trachyandesite.
[5] Basalt.

TABLE 4.—*Normative minerals (weight percent) in Tertiary igneous rocks*

[All rock names are according to Rittmann (1952, p. 75–102) classification. CIPW procedure. H_2O and CO_2 are omitted and remaining analyses are normalized to 100 percent.]

	Map unit: rhyolite (Tir)					Map unit: rhyolitic flow breccia (Trb)	Map unit: quartz latite (Tql)			
Sample	1	2	3	4	5	6	7	8	[1]9	10
Quartz	34.9	32.0	30.3	25.6	7.8	34.9	19.2	13.3	13.1	11.4
Corundum	1.8	1.3	1.4	1.0		.5	2.1			
Orthoclase	26.4	25.2	27.7	30.4	29.4	25.4	25.2	21.2	18.2	19.4
Albite	33.4	37.8	34.5	35.0	23.8	32.0	37.1	34.7	38.2	36.5
Anorthite	2.1	2.6	3.6	4.8	7.8	4.4	11.1	14.1	16.0	13.8
Nepheline										
Diopside					16.7			4.5	1.1	4.7
Hypersthene	.5	.7	.3	.8	6.2	.5	.9	5.6	6.4	7.3
Olivine										
Magnetite	.2	.4			4.1			2.7	3.0	4.5
Hematite	.6		1.8	1.8		1.7	3.1	1.7	1.6	
Ilmenite	.1	.04	.2	.3	1.9	.3	.6	1.4	1.7	1.6
Titanite										
Rutile			.2	.1		.1	.3			
Apatite	.01	.02	.05	.3	2.3	.1	.6	.9	.9	.9

	Map units: rhyodacite (Tird and Trrd)						Map unit: rhyodacitic volcanic ash (Tra)	Map unit: trachyte (Tt)			
Sample	11	12	13	14	15	16	17	[1]18	19	[2]20	21
Quartz	12.9	21.4	11.8	11.6	15.0	8.5	43.3	9.6	8.4	3.6	
Corundum		2.6			.5		4.6				
Orthoclase	18.2	19.2	17.7	19.1	16.8	18.1	14.2	17.2	28.2	26.9	31.6
Albite	37.4	35.6	35.0	33.8	33.2	33.3	16.6	34.4	28.9	28.0	27.8
Anorthite	15.4	10.6	14.3	20.5	17.0	20.7	10.4	14.9	10.7	11.5	8.2
Nepheline											
Diopside	3.2		4.8	.2		.3		8.9	6.2	9.2	11.4
Hypersthene	6.2	1.4	8.8	6.5	6.5	13.5	4.3	9.0	6.7	10.7	6.0
Olivine											4.0
Magnetite	3.3		3.1	4.7	3.2	1.9		3.2	3.2	5.2	5.5
Hematite	1.1	6.4	1.8		3.8		5.6		2.3		.4
Ilmenite	1.5	1.2	1.6	2.5	2.5	2.5	.3	1.9	3.3	3.1	2.9
Titanite											
Rutile		.5					.3				
Apatite	.9	1.1	.9	1.2	1.5	1.2	.3	.9	2.0	1.8	2.3

	Map units: latite (Tl and Trl)					Map units: trachyandesite (Tta and Trta)											
Sample	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	[3] 38
Quartz	12.7	2.5	3.5			13.1	4.7	7.7	3.8	2.7	2.7	6.7	1.5	3.2	5.9	3.9	7.1
Corundum	1.4					1.5											
Orthoclase	27.6	27.0	23.0	22.5	17.4	20.6	22.3	16.5	19.6	16.9	16.7	18.6	18.9	20.0	12.2	11.2	8.2
Albite	42.0	41.3	32.9	45.6	25.8	34.6	38.9	36.4	36.0	38.1	35.5	35.5	35.8	35.8	28.0	26.7	23.5
Anorthite	9.5	12.9	12.9	11.7	14.4	19.7	21.2	18.5	19.5	19.9	19.5	22.5	18.0	18.6	22.5	23.5	28.4
Nepheline				2.0	2.3												
Diopside		3.6	9.1	1.2	14.4			4.1	3.7	8.3	5.9	4.2	8.2	6.7	12.4	19.7	12.3
Hypersthene	1.2	2.4	7.2			.1	1.8	10.5	6.5	2.8	11.4		6.7	5.6	7.5	1.8	8.1
Olivine				4.2	17.3												
Magnetite			4.6	2.0	3.7			2.8	1.2	6.0	4.3	.5	2.9	5.6	7.3	7.6	7.9
Hematite	3.5	6.0	2.0	5.5		6.5	6.4		5.2	2.1		5.9	3.5	.4		1.1	
Ilmenite	1.3	1.6	3.1	2.8	3.1	.7	2.4	2.4	3.0	1.7	2.8	2.8	3.3	3.0	2.9	3.4	3.3
Titanite		1.5					.8										
Rutile	.02					1.5	.06										
Apatite	.7	1.3	1.7	2.4	1.6	1.9	1.5	1.1	1.5	1.5	1.2	1.9	1.1	1.2	1.2	1.2	1.2

	Map units: trachybasalt (Ttb and Tytb)												Map unit: basanite (Tb)
Sample	[4] 39	40	[5] 41	42	43	44	45	46	47	48	49	50	51
Quartz	10.3	4.1	0.2	2.9		4.2		1.6	8.3				
Corundum													
Orthoclase	13.5	11.4	7.8	14.0	12.9	10.2	13.9	12.7	12.5	10.2	9.0	14.1	17.3
Albite	35.2	27.5	26.5	28.8	26.3	24.1	26.8	24.3	26.8	28.4	17.6	22.1	8.0
Anorthite	23.7	21.3	24.3	18.5	20.1	22.1	18.1	19.4	23.6	20.1	22.7	25.0	23.2
Nepheline											4.9	1.4	2.6
Diopside		11.2	14.3	14.1	12.6	15.2	18.6	17.6	5.5	14.5	22.5	6.6	25.6
Hypersthene	3.1	14.4	18.9	8.6	12.9	9.3	8.6	9.8	4.3	2.2			
Olivine					7.0		.9			9.8	10.8	15.5	8.9
Magnetite		6.5	4.0	5.5	5.4	9.7	8.9	8.7		9.0	6.2	7.4	8.0
Hematite	8.6			3.5				1.6	13.6				
Ilmenite	1.5	2.5	3.1	2.7	1.4	3.3	3.1	3.1	2.6	4.2	4.8	6.0	4.5
Titanite	2.3								1.3				
Rutile	.2												
Apatite	1.5	1.0	1.0	1.4	1.6	1.8	1.1	1.2	1.5	1.7	1.6	1.9	1.9

[1] Rhyodacite.
[2] Latite.
[3] Andesite.
[4] Trachyandesite.
[5] Basalt.

RABBIT EARS VOLCANICS AND YOUNGER EXTRUSIVE ROCKS

The largest outcrop of Rabbit Ears Volcanics, at the east edge of the Whiteley Peak quadrangle, is a thick pile of extrusive rocks, predominantly breccia and associated pyroclastics but also including intercalated trachyandesite flows. Extrusive rocks elsewhere include breccia, volcanic ash, agglomerate, and flows of latite, trachyandesite, and trachybasalt.

Nomenclature.—Much of the Rabbit Ears Range which separates North Park from Middle Park is composed largely of breccia and other volcanic rocks. These rocks have for many years been informally referred to as the Rabbit Ears Volcanics, the name being taken from the Rabbit Ears Range. Recently, Izett (1966) formally established the name for these rocks in northern Middle Park and southern North Park.

To avoid a possible confusion in names, it is noted that Rabbit Ears Peak is geographically part of the Park Range and not of the Rabbit Ears Range, which lies farther east.

BRECCIA

By far the largest proportion of the Rabbit Ears Volcanics and younger extrusive rocks is breccia. Although the dominant rock type is pyroclastic breccia, other lithologic types occur in varying amounts: ash, tuff, lapilli tuff, flow breccia, agglomerate, and possibly water-worked volcanic conglomerate. The breccia may attain a maximum thickness of as much as 1,000 feet within the mapped area, and doubtless is much thicker east of the area.

Small blocks of breccia are abundant in the area mapped as landslide in the northern and eastern parts of the Whiteley Peak quadrangle and the southeastern part of the Spicer Peak quadrangle. Many of these blocks are large and appear unbroken; such blocks, for example, make up the landslide masses in secs. 24 and 25, T. 4 N., R. 81 W., and it is possible, though unlikely, that such masses could be true outliers rather than slide blocks. Much of the enormous quantity of rubble shown on the map as landslide or colluvium near the main breccia outcrops has been derived from disintegration of the breccia.

The pyroclastic breccia forming both the mass at the east margin of the Whiteley Peak quadrangle and the large outliers to the west includes several lithologic varieties but typically consists of poorly sorted angular fragments of volcanic rock set in a fine-grained tuffaceous matrix which is predominantly glass and much opaque material. The megascopic fragments range widely in size, from lapilli to large blocks several feet in length. These fragments comprise a variety of volcanic rock types that range from trachybasalt to rhyolite in various textures. Fragments of trachyandesites and trachybasalts, many of them scoriaceous, are by far the most abundant, but locally the dominant fragmental rocks are porphyritic trachyandesites or rhyolites. The ratio of matrix material to megascopic fragments is highly variable but probably averages about 2 or 3 to 1.

The pyroclastic breccia is dominantly medium to dark brownish gray and ranges from dark gray to very light gray. Some of the rock is brick red. In most exposures, the matrix material is brownish gray and the larger fragments are darker. In the red breccias, both matrix and fragments are commonly red.

The breccia generally weathers readily, and most exposed surfaces are littered with the debris of volcanic rock fragments. On the whole, however, the breccia is a fairly resistant rock.

A locally conspicuous red pyroclastic breccia is present near the trachybasalt intrusive just southwest of White Slide Mountain and may have formed during the instrusion. The matrix of the breccia is red to salmon-pink tuff which contains angular fragments predominantly of brick-red scoria and of lesser amounts of other volcanic rock types. These fragments range in size from lapilli to blocks several feet in length. The lower slopes of the prominent hill in the W½ sec. 12, T. 4 N., R. 80 W., and the basal western slopes of White Slide Mountain are composed of this breccia. Minor amounts of red breccia also occur elsewhere in the area.

Some of the breccia was evidently deposited or reworked by water. The excellent exposures in the cliff southeast of White Slide Mountain (center sec. 7, T. 4 N., R. 80 W.) are composed mostly of very light gray lapilli tuff, showing conspicuous bedding and cut-and-fill channels (fig. 5). Although White Slide Mountain takes its name from this conspicuous cliff of lapilli tuff, the crest of White Slide Mountain is composed of dark pyroclastic breccia. The lapilli tuff consists mostly of consolidated ash that contains small fragments of porphyry, flow rocks, and pumice. The rock fragments are apparently altered and bleached, and the pumice is altered to white clay. Local concentrations of blocks and boulders of various volcanic lithologic types are arranged in beds suggestive of sorting by water. Many of the boulders are somewhat rounded. Apparently this type of breccia or volcanic conglomerate is present also on the upper slopes between Red Slide and White Slide Mountains, where it locally is altered to an ashy clay.

The breccia composing the Chimney Rock outlier and the breccia outlier to the west generally resemble the pyroclastic breccia compos-

FIGURE 5.—Light-gray lapilli tuff, breccia, and volcanic conglomerate in Rabbit Ears Volcanics. Cut-and-fill channels and dark beds of rounded boulders suggest deposition by water. Center sec. 7, T. 4 N., R. 80 W., southeast of White Slide Mountain.

ing the bulk of the Rabbit Ears Volcanics. However, it contains abundant rounded grains and calcite cement and displays crude bedding suggestive either of reworking or deposition by water.

An apparent flow breccia, possibly as much as 250 feet thick, crops out in sec. 31, T. 5 N., R. 80 W. (approximately) and in adjacent sections along the switchback road that climbs to the crest of the Rabbit Ears Range. The breccia is light brownish gray, very hard and resistant, and consists of fragments of a gray felsic rock set in a tuffaceous lighter gray matrix of similar rock. The rock has the normative composition of a rhyolite (sample 6, table 4). The megascopic fragments are probably rhyolite. Microphenocrysts are mostly feldspar, which is sanidine and plagioclase in about a 3 to 1 ratio. Biotite is a conspicuous accessory. Minor clinopyroxene is also present. Quartz probably occurs with feldspar in the glassy to cryptocrystalline groundmass. The matrix of the breccia is fine-grained glass, which includes some shards, and abundant feldspar microlites with a trachytic texture. The matrix is dense to finely granular and is so strongly lithified that fractures form across the enclosed fragments. Little Haystack Mountain, a rhyolite intrusive, may have been the source for this breccia, as the rocks are similar compositionally, but such a relationship cannot be demonstrated conclusively.

Several types of breccia occur on and near Rabbit Ears Peak; all are related to the volcanic center (map unit) located just west of the peak in the NE¼ sec. 5, T. 5 N., R. 82 W. They are part of a complex volcanic sequence which also includes dikes and flows peripheral to the central Rabbit Ears Peak plug.

A mudflow breccia, or volcanic conglomerate, crops out in the saddle just west of the central Rabbit Ears Peak plug and also underlies nearly all the trachybasalt flow to the west. Near the plug, this breccia in its lower part is tan to salmon pink and contains mostly fragments of Precambrian crystalline rocks as its coarse constituents. Some fragments are subrounded boulders as much as 2 feet long. The Precambrian crystalline rocks doubtless were derived from fragments in the Coalmont Formation into which the plug was intruded. The matrix is ash, pumice, and other eruptive material, and much fine arkosic detritus, all rather loosely cemented.

Another type of breccia crops out adjacent to the east side of the central Rabbit Ears Peak plug. It is a red agglomerate composed entirely of blocks and fragments of scoria and bombs. Just east of this breccia is a breccia composed entirely of angular blocks of dark trachybasalt, most of them scoriaceous. The cementing material in both breccias is amorphous to crystalline calcite. Overlying the eastern breccia and probably gradational from it is a breccia composed of smaller trachybasalt fragments firmly embedded in a predominantly noncalcareous tuff matrix. At least two mafic dikes occur within these breccias but are too small to be shown on the geologic map (pl. 2).

The Rabbit Ears themselves are two columnlike outliers of breccia, which stand in part on trachybasalt flows. The larger fragmental constituents are red to nearly black scoria and trachybasalt blocks as much as 8 feet long. They are set in a matrix of smaller fragments of volcanic material, mostly of red to black scoria, firmly cemented by amorphous to crystalline calcite. This breccia forms a fairly resistant unit.

Small patches of breccia similar to each other in lithology crop out at three localities: half a mile northwest of the Murphy Ranch in sec. 22, T. 6 N., R. 81 W. and just south of Grizzly Creek in sec. 3, T. 5 N., R. 81 W. (both localities in the Spicer Peak quadrangle); and in secs. 5 and 6, T. 5 N., R. 81 W. (Rabbit Ears Peak quadrangle). All three of these patches are associated with mafic dikes and probably represent small local volcanic centers. The breccia is typically dark yellowish to brownish gray and is composed mostly of lapilli-size angular fragments cemented by clay presumably derived from altered ash. Locally the breccia is calcareous, and its weathered surfaces resemble impure coarse conglomeratic sandstone. Most of the rock fragments appear to be mafic tuffaceous rocks, but some flow or intrusive rock fragments are also present. Large blocks are sparse but occur locally, as in the outcrop south of Grizzly Creek. Quartz and arkosic grains are fairly abundant and presumably were derived from the enclosing Coalmont Formation.

Another breccia associated with a mafic intrusion crops out on the southwest slope of North Ryder Peak. The intrusive body of trachybasalt that forms the peak is in line with two northwest-trending dikes to the northwest and probably represents the local center from which the breccia was derived. The matrix of the breccia is mostly brownish-gray lapilli tuff, similar to the breccia described in the preceding paragraph, but the unit differs in containing large angular blocks of dark mafic rocks as much as 4 feet long. The cementing material is clay and calcite. This breccia as a whole resembles the pyroclastic breccia of the main mass of Rabbit Ears Volcanics to the east.

A notable mass of breccia is represented by the two small outcrops in sec 31, T 4 N., R 81 W. (Lake Agnes quadrangle) and by breccia in the large landslide area to the northeast. Much of the landslide material in sec. 19, T. 4 N., R. 81 W., is also probably derived from breccia. Several breccia types are well exposed in a 60-foot sequence at the southernmost of the two breccia outcrops in sec. 31, T. 4 N., R. 81 W. The lower part is a moderately resistant ash-flow breccia containing small fragments of volcanic flow rock. The middle part is a coarse pyroclastic breccia containing abundant angular blocks of mafic rocks set in a tuff matrix. The top, apparently gradational from the middle unit, is a strongly welded flow breccia. The entire sequence fills a narrow valley cut in the Pierre Shale. A large quantity of breccia evidently capped the high ground in this area and has now been moved down the hillsides as landslides. These slides consist mostly of breccia, or material derived from breccia, but also contain much ash and limy material from the North Park Formation. The size and unbroken condition of abundant jumbled blocks of breccia suggest that the blocks have not moved far downslope from their original position, probably half a mile or less. The original source of this abundant breccia is not known. The few dikes nearby seem to be too small to constitute a significant volcanic center. Possibly the source was Whiteley Peak, a large intrusive about 3 miles to the north.

Source of the breccia.—Although a few obvious intrusive centers occur in the mapped area, the source for most of the breccia of the Rabbit Ears Volcanics probably lies to the east. The remaining widely scattered intrusive bodies west of the Rabbit Ears Volcanics indicate that many local eruptive centers contributed to the supply; probably many of these are now covered by the breccia.

RHYODACITE

A single small patch of extrusive rhyodacite crops out in the southwest corner of the Rabbit Ears Peak quadrangle. It is part of a flow that lies on Precambrian rocks and on the Chugwater Formation west of the Rabbit Ears Peak quadrangle. The rhyodacite is light gray, fine grained to dense, and locally vesicular. Just west of the map boundary, it is very dark gray and weathers to mottled dark gray or reddish gray. Within the mapped area, the flow may be as much as 100 feet thick. Its source is not known.

The rock in thin section is mostly nonporphyritic. Sparse phenocrysts appear to be andesine, which is much corroded and altered; these may be xenocrysts. Limonite and clay are abundant and apparently fill small vesicles. The groundmass is intergranular, largely cryptocrystalline, apparently mostly feldspar, but also contains many opaque grains, that include limonite and fairly abundant quartz.

VOLCANIC ASH

A small deposit of bedded volcanic ash crops out on the south side of the upper slopes of Rabbit Ears Peak. It lies on the Coalmont Formation and underlies various volcanic extrusive rocks related to the Rabbit Ears Peak volcanic center. It may represent a separate and earlier stage of volcanic activity, or may actually represent an initial phase of the volcanism of the Rabbit Ears Peak volcanic center. The latter seems more likely, inasmuch as a thin ash bed of similar lithology apparently overlies a flow of trachybasalt in the overlying volcanic sequence.

The volcanic ash is very fine grained to silty, crudely even bedded, friable and nonresistant, and light reddish brown to salmon pink. The color of the outcrop makes it conspicuous when viewed from a distance. The lower beds of the unit contain some arkosic grit-size fragments probably derived from the underlying Coalmont Formation. The upper 1–2 feet appears to be an ancient regolith containing various volcanic rock types and rounded cobbles of Precambrian intrusive rocks in a breccialike mass that was baked and fused by the overlying flow. The unit has a maximum thickness of about 120 feet, but it thins abruptly in all directions, presumably because of erosion. It is absent on the north side of the ridge, only a few hundred feet distant.

The ash has a rhyodacitic composition (sample 17, tables 2–4). Thin-section examination shows it to be predominantly a vitric ash containing abundant crystal fragments of mostly potassium feldspar and quartz.

QUARTZ LATITE TUFF

Quartz latite tuff was found only as float at various places in the area. Notable concentrations, for example, are present on the south slopes below the breccia mass of Chimney Rock, on the east slopes below the trachyandesite flow of Dennis Hump, and along the road in the S½ sec. 25, T. 5 N., R. 81 W. Although its true position is unknown, the tuff apparently lies at the base of the Rabbit Ears Volcanics, as indicated by the topographic position of the concentrations of float.

The rock is distinctive from any other volcanic unit in the area. It is hard and strongly lithified, light gray to white, and porphyritic. Thin-section examination shows that the tuff is about 90 percent glass in the form of nonwelded pumice bubbles, shards, and dust. Most of these show weak birefringence. The phenocrysts are mostly euhedral quartz and sanidine and sparse oligoclase.

LATITE

A poorly exposed latite flow as much as 100 feet thick caps a low wooded hill about a mile northeast of Dennis Hump in the southeastern part of the Spicer Peak quadrangle. The latite is medium gray to grayish purple, slightly porphyritic, and dense to vesicular. In thin section (sample 23, tables 2–4), microphenocrysts of andesine, hornblende, and clinopyroxene lie in a felty groundmass of feldspar microlites and sparse mafic minerals. Euhedral andesine phenocrysts are the most abundant and reach 2 mm in length. Light-yellow to reddish-brown hornblende phenocrysts are also abundant and range in length from 1 to 3 mm. Small amounts of euhedral clinopyroxene, apparently augite, also are present as phenocrysts. The groundmass is mostly plagioclase microlites and irregular masses of low birefringent cryptocrystalline material; also present are minor amounts of opaque grains and hornblende.

TRACHYANDESITE

A flow of trachyandesite lies beneath the breccia cap of Dennis Hump. A nearly identical flow rock crops out in the main mass of Rabbit Ears Volcanics on the switchback road in the SE¼ sec. 31, T. 5 N., R. 80 W. (approximate location in an unsurveyed township), and a somewhat different type rock crops out about ¼–½ mile to the east. The rock is light purplish gray to medium grayish purple, in part vesicular and amygdaloidal, and slightly porphyritic. The small phenocrysts are pyroxene and feldspar. Vesicular texture where best formed is displayed by rocks with oval vesicles as much as 1 cm long. Many vesicles are filled with calcite. The trachyandesite of the outcrop east of the switchback road is lithologically dissimilar from the vesicular type. It is very fine grained, nearly aphanitic, and may be more felsic than the vesicular trachyandesite.

At Dennis Hump, the vesicular trachyandesite is 500 feet thick on the east side, but the base is not exposed. It is a resistant unit and forms steep cliffs and slopes. The outcrop at the switchback road is lenticular, perhaps a channel flow enclosed by breccia, and reaches a maximum thickness of about 100 feet. The outcrop east of the switchback road has a maximum thickness of about 200 feet and weathers out in crudely platy masses. In thin section the rock is microporphyritic. Sodic laboradorite and augite phenocrysts lie in an intergranular to felty groundmass of plagioclase and potassium feldspar microlites, very fine opaque grains, and altered pyroxene. Clay-filled amygdules are abundant.

Red Slide Mountain takes its name from the conspicuous steep cliff on its lower slopes formed mainly in a thick red-weathering porphyritic trachyandesite flow. Colors of the fresh rock vary from dark to medium greenish gray and light grayish purple. Megascopically the rock contains abundant small but conspicuous phenocrysts of hornblende and less conspicuous feldspar. The unit weathers to a very rough irregular surface. Colors of the weathered rock range from olive green to reddish brown. There is no indication of individual flows within the unit. Its maximum thickness is 440 feet, but it thins and disappears very abruptly both to the north and south, and it is apparently absent farther east, although slope rubble may conceal its outcrop. Abundant concentration of rubble of the trachyandesite on the west slopes of the prominent hill in the W½ sec. 12, T. 4 N., R. 81 W., may represent an outlier of the flow. The basal contact of the flow is exposed at the foot of Red Slide Mountain. It rests on a pyroclastic breccia about 30 feet of which is exposed locally above the colluvium. The basal 10–15 feet of the flow is dark greenish gray, is probably more mafic than most of the unit, and grades upward into lighter colors more typical of the unit as a whole. Locally the top of the unit is brecciated, and thin-section examination shows a porphyritic texture. Abundant phenocrysts of hornblende, feldspar, and minor amounts of irregular masses of brown cryptocrystalline glass lie in an intergranular cryptocrystalline felsic matrix. Feldspar phenocrysts are labradorite and sanidine in a ratio of 2 or 3 to 1.

Numerous small flows occur in the pile of breccia mostly east of White Slide Mountain. Most of these flows are trachyandesites, but they probably range in composition from trachyandesite to rocks somewhat less felsic. Some of the flows are too small to show on the geologic map (pl. 3), and probably others are concealed by the abundant surface wash derived from the breccia. Colors of the trachyandesite are medium gray, dark gray, or black. Textures are dense to slightly porphyritic, or vesicular and amygdaloidal. Visible phenocrysts are altered olivine and pyroxene. Irregularly shaped amygdules are filled either with clay or crystalline calcite. Flow breccia is present locally, mostly at the top or bottom of the flows. Most of the flows are thin relative to their width of exposure. They appear to be lenticular, none apparently having great areal extent, and they probably flowed in channels or low areas in the surrounding breccia at various times during the eruptive cycle. Thickness of the flows ranges from a few feet to 150 feet. The thick body at the east edge of the Whiteley Peak quadrangle is interpreted as a thick flow, but relationships to surrounding rocks are obscure and the unit may be, at least in part, intrusive. This trachyandesite in thin section is vesicular and microporphyritic. The darker and less porphyritic rocks have phenocrysts of augite and olivine (or iddingsite after olivine) in an intergranular groundmass of feldspar and lesser amounts of iddingsite, augite, and opaque grains. The lighter and more porphyritic rocks also have abundant phenocrysts of labradorite and some potassium feldspar. Most filled vesicles contain calcite; a few contain clay. Small amounts of glass are present in the darker samples.

A small isolated flow of trachyandesite crops out in sec. 29, T. 5 N., R. 82 W. The unit as shown on the map (pl. 3) also includes a 5- to 10-foot-thick bed of white to pink volcanic ash and tuff underlying the trachyandesite flow which is about 25 feet thick. The trachyandesite is mostly medium purplish gray, slightly porphyritic, vesicular, and amygdaloidal. The visible phenocrysts are altered hornblende and pyroxene. A few vesicles are filled with quartz. Thin-section examination shows sparse phenocrysts of oxyhornblende almost entirely altered to opaque grains, clinopyroxene, and sparse plagioclase, in a groundmass of intergranular texture. Groundmass minerals are mostly sodic andesine, potassium feldspar, a lesser amount of clinopyroxene, and unidentified opaque grains.

TRACHYBASALT

Only two rather small patches of extrusive trachybasalt crop out in the area, but abundant and widespread trachybasalt rubble litters many hills, especially in the northern part of the area. One outcrop of trachybasalt lies about half a mile west of Rabbit Ears Peak. This outcrop is the east end of a fairly large flow which extends 2 miles to the northwest into the adjoining Mount Werner quadrangle. This outcrop forms the crest of the Continental Divide and reaches elevations of above 10,600 feet.

Within the mapped area the flow lies on volcanic breccia and probably conglomerate of the Coalmont Formation. At its northwest end near Fishhook Lake in the Mount Werner quadrangle, the flow lies on Precambrian rocks. At this locality, limestone identical to that of the North Park Formation in North Park, except for containing larger Precambrian granitic rock fragments, lies intercalated between trachybasalt flows.

The eruptive center just west of Rabbit Ears Peak constitutes one source of the trachybasalt flows. An apparent feeder dike is present at the southeast corner of the flow to the west, but is not mapped separately. It is nonvesicular, as contrasted to the flown rock that is abundantly vesicular.

The small patch of flow rock under Rabbit Ears Peak is mostly weathered but is similar to the trachybasalt to the west and is mapped as trachybasalt.

Large blocks of trachybasalt cap Pole Mountain in the Coalmont quadrangle, and abundant rubble is also present on the top and slopes of Mexican Ridge. Some of this rubble is thick enough to be mapped as colluvium. It is evident that a very widespread flow or series of flows at one time covered a large area, at least as far north as Pole Mountain. At Pole Mountain and Mexican Ridge, the trachybasalt rubble apparently overlies ashy limestone rubble derived from the North Park Formation of late Miocene age. The volcanic center near Rabbit Ears Peak is a probable source of some of the trachybasalt flow rock, but there are probably other sources, for example, at Spicer Peak. The rock of the outcrop west of Rabbit Ears Peak is virtually identical with the rubble blocks on Pole Mountain, Mexican Ridge, and at some other places, except that it contains scoriaceous material. The rock is medium purplish red to purplish black and is mostly vesicular and commonly amygdaloidal. Sparse flow breccia occurs also. Within the area, the unit is as much as 350 feet thick and may be a series of flows rather than a single one.

Microscopic study of the rock near Rabbit Ears Peak shows the trachybasalt to be sparsely microporphyritic. Phenocrysts of clinopyroxene and olivine ghosts lie in a groundmass of intergranular texture. The groundmass consists mostly of opaque grains probably derived from olivine, sodic labradorite, and a minor amount of intergranular clinopyroxene. A sample (no. 44, tables 2–4) of trachybasalt rubble from Mexican Ridge is similar in most respects to the rock near Rabbit Ears Peak. The texture is felty. The larger microphenocrysts are olivine as much as 1 mm in length, mostly altered to iddingsite. The groundmass is principally labradorite and lesser amounts of potassium feldspar, clinopyroxene, unidentified opaque grains, and sparse altered olivine.

INTRUSIVE ROCKS

RHYOLITE

Two large and several small bodies of intrusive rhyolite crop out in the mapped area. The largest is at Little Haystack Mountain in the southeast corner of the Spicer Peak quadrangle. Another large intrusive is at the hill a mile northeast of Whiteley Peak, in the Whiteley Peak quadrangle. Small outcrops are present near Indian Creek and near the Haworth Ranch in the Whiteley Peak quadrangle, and near the Smole Sawmill and near Diamond Creek in the Lake Agnes quadrangle.

The rhyolites are mostly light gray and less commonly grayish purple, grayish red, or greenish gray. They are porphyritic to dense. In thin section, most of them have a groundmass of intergranular to hyalopilitic texture. The ratios of groundmass to phenocrysts range from about 20 to 1 to about 3 to 1. Phenocrysts are predominantly sanidine and lesser amounts of plagioclase (generally oligoclase), sparse biotite, and quartz. The groundmass is mostly cryptocrystalline to partly glassy and chiefly contains potassium feldspar and quartz as the identifiable minerals; small amounts of opaque dust, biotite, and pyroxene may also be present.

Little Haystack Mountain is an irregular crudely cone shaped hill that covers an area of about three-quarters of a square mile and that rises 1,500 feet above its base at the South Fork of Arapaho Creek. It is surrounded by surficial rubble so that its true relationship to adjacent rock units is not clearly known. Grout (in Grout and others, 1913, p. 47) interpreted it as an intrusive body, apparently a laccolith. Its shape and its proximity to the edge of the breccia pile of Rabbit Ears Volcanics suggest that it was intruded into the breccia. The presence of rhyolitic flow breccia about 2 miles distant in the Rabbit

Ears Volcanics suggests that the Little Haystack body may have penetrated the volcanics at an early stage of their accumulation and may have been a source of some of the eruptive material. If so, however, later erosion has removed flows or breccia units that could be directly related to the Little Haystack body. Little Haystack itself does not appear to be constructed of flow units, although in places there is suggestion of layering or flow banding.

About a mile northeast of Whiteley Peak is a prominent unnamed hill, locally called Burnt Timber Mountain, composed of intrusive rhyolite. The outcrop of rhyolite is less than a quarter of a square mile in area, and a small patch of the same rock crops out a quarter of a mile to the south. Grout (in Grout and others, 1913, p. 47) classified this unit as a laccolith. The roughly domical shape of the hill suggests a laccolithic structure, but there is no clear evidence of doming of the intruded sedimentary rocks. The unit clearly crosscuts the Pierre Shale at one locality and very probably intrudes the Middle Park Member of the Coalmont Formation, although exposures of the contact of the rhyolite with the Middle Park are lacking. At a good exposure of the contact of the intrusive with the Pierre Shale on the southeast slope of the hill, dark clay shale, which is normally soft and nonresistant, is baked to a hard brittle platy rock for a few inches away from the contact.

Three obscure bodies of rhyolite crop out within half a mile east of Indian Creek in the northeastern part of the Whiteley Peak quadrangle. All are surrounded by very abundant coarse rubble of volcanic material, and their relation to adjacent rock units is not known. The shape of the bodies and their texture suggest that they are intrusive.

Rhyolite crops out in a low inconspicuous knob and in a small gully about half a mile north of Whiteley Peak Reservoir. The small body of rhyolite in the knob is mainly a concordant intrusive—a thickened sill. The small southernmost outcrop is intrusively intercalated with the east-dipping Pierre Shale. Much of the rock is thin layered, platy, and even fissile. The Pierre Shale in the immediate vicinity of the intrusive is baked to a brittle platy rock.

The conspicuous low ridge just east of the Haworth Ranch at the junction of Muddy and Lindsay Creeks is capped by a light-gray to white dike rock which is thinly layered, almost fissile, and brittle. This rock was not examined petrographically but resembles the thin-layered rhyolite which intrudes the Pierre Shale north of Whiteley Peak Reservoir.

A thin discontinuous dike, culminating in a small, sharp peak at its northwest end, crops out just east of the Smole Sawmill. The rock differs from the other rhyolites. It is medium to dark greenish gray and is slightly porphyritic; the visible phenocrysts are biotite. In thin section, phenocrysts of biotite, augite, and calcite (from augite) lie in a groundmass of felty to intergranular texture. The ratio of groundmass to phenocrysts is about 10 to 1.

QUARTZ LATITE

The intrusive quartz latite forming Whiteley Peak is the largest and most prominent body of this rock type in the area. A small quartz latite dike caps Carter Mountain. The quartz latite is light to medium greenish gray but locally dark gray or light brownish gray; is chiefly porphyritic but fine grained to dense in some varieties.

Whiteley Peak is one of the most prominent landmarks in northwestern Middle Park. Its crest, which is unusually sharp and narrow, stands 2,200 feet above the valley of Muddy Creek; precipitous cliffs mark the southwest face just below the summit. Intrusive rock forms the upper 800–1,000 feet of the peak.

The intrusive rock of Whiteley Peak is mainly a crosscutting body, very probably a plug, but there is some evidence that it may, in part at least, have been intruded into the Pierre Shale concordantly with the bedding. An outcrop at the base of the steep cliff on the west face shows the intrusive lying on a fine-grained sandstone of the Pierre Shale. Apparently the contact is nearly horizontal or slightly west dipping, but the exposure is not large enough to show the relationship clearly. On its east-dipping eastern slope a small patch of Pierre Shale is altered and baked near the contact. The satellite intrusion just southeast of the main body is a sill. Probably a feeder moving up along the steep fault extending south from Whiteley Peak crosscut the sedimentary beds to a shallow depth, then intruded concordantly with the east-dipping regional structure of the Pierre Shale on the west side of the fault, and abruptly thickened as it moved updip. The quartz latite apparently intruded nearly flat-lying conglomeratic sandstone of the Middle Park Member of the Coalmont, which is seen in rubble and obscure outcrops on the north flank of the mountain. Its mode of occurrence appears generally similar to that of the bodies at Bear Mountain and Baker Mountain which are in part, at least, concordant intrusives. No known extrusive volcanic rocks occur in the immediate vicinity of Whiteley Peak, but only 3 miles south large landslide masses contain breccia (see discussion of Breccia, p. 62) and other volcanic material. Whiteley Peak is a possible source for this material.

The rock composing Whiteley Peak ranges from light-greenish-gray porphyritic quartz latite and rhyodacite to very dark gray trachyandesite. Quartz latite is the predominant rock type and grades from very dark greenish gray slightly porphyritic to light-greenish-gray porphyritic rock. The darker less porphyritic quartz latite commonly weathers to sharp square-faced angular outcrops. Sheeting and jointing are common. Excellent columnar jointing is formed on the cliffs of the west face of the peak. The porphyritic quartz latite is resistant, but tends to weather into more rounded outcrops, and on the gentler slopes, outcrops are covered by gruslike material consisting of weathered-out phenocrysts. The top of the peak is light-colored porphyritic quartz latite. Smooth surfaces of both porphyritic and less porphyritic types weather reddish brown.

The sill cropping out just southeast of the main body of Whiteley Peak intrudes the Pierre Shale and is porphyritic quartz latite. The enclosing shale is baked to a hard brittle rock for a few feet away from the contact.

Microscopically, the light-colored porphyritic quartz latite shows abundant large phenocrysts in a groundmass of intergranular texture. The ratio of groundmass to phenocrysts is about 3 or 4 to 1. The phenocrysts include andesine, biotite, augite, quartz, and hornblende. About three-fourths of the phenocrysts are sodic andesine (An_{30-33}). The groundmas is mostly feldspar, potassium feldspar being more abundant than plagioclase in a ratio of 2 to 1 or slightly more. Quartz grains, cloudy with inclusions, are fairly abundant. Lesser amounts of clinopyroxene and opaque grains are present in about equal proportions. Minor accessory minerals include biotite, apatite, and hornblende. The darker quartz latite is quite similar to the lighter rock in thin section, except that the phenocrysts are generally smaller and quartz and biotite do not occur in the groundmass. Also, a few sanidine phenocrysts are present. The darker color is probably due to a larger proportion of groundmass pyroxene.

Trachyandesite makes up a small part of the intrusive body at Whiteley Peak. The trachyandesite is very dark gray, almost black, and slightly porphyritic to dense. In thin section the rock is microporphyritic. The phenocrysts are olivine or iddingsite and clinopyroxene in roughtly equal proportions. A few feldspar and quartz grains, apparently xenocrysts, are also present. The groundmass is mostly cryptocrystalline, containing potassium feldspar and labradorite in roughly equal proportions and minor amounts of quartz. The rest of the groundmass includes fairly abundant clinopyroxene and somewhat lesser amounts of olivine and unidentified opaque grains.

Carter Mountain is a prominent hill in the southern part of the Whiteley Peak quadrangle. At its peak is a small dike of quartz latite, which is medium to light brownish gray. The latite weathers to darker shades and has a vague mottling or color banding on smooth or cut surfaces. The quartz latite is dense and has only sparse barely visible phenocrysts of biotite and feldspar. In thin section, very sparse phenocrysts of euhedral sodic labradorite, elongate biotite crystals as much as 1 mm long, and some irregular masses of limonite lie in a pilotaxitic to intergranular groundmass consisting mostly of cryptocrystalline felsic minerals and fairly abundant opaque grains. The largest grains in the groundmass are plagioclase.

A rhyodacite dike at Muddy Pass intrudes the Benton Shale and Niobrara Formation and has altered and locally brecciated the intruded rocks. The rhyodacite itself is much contaminated by secondary calcite. The rock is porphyritic and light gray to light yellowish gray and contains conspicuous euhedral feldspar phenocrysts as long as 1 cm and abundant small irregularly shaped masses of limonite. Thin-section examination shows that the large feldspar phenocrysts are zoned oligoclase. Altered biotite and clinopyroxene are fairly abundant; quartz and corroded hornblende are sparse. A hyalopilitic groundmass is potassium feldspar, plagioclase, and glass in roughly equal proportions and sparse clinopyroxene.

The rhyodacite body that U.S. Highway 40 crosses just south of Muddy Pass intrudes the Niobrara Formation and has baked it to a very hard hornfels within a few feet along the contact. At its north end the rhyodacite is concordantly intercalated with gently east dipping shale beds of the Niobrara, but at the outcrop cut by Highway 40, it crosscuts the beds of the Niobrara almost at right angles. The rhyodacite is only slightly porphyritic and ranges in color from tan to dark greenish gray. Sparse anhedral quartz, apparently xenocrysts, are as much as 2 mm long. The groundmass texture is hyalopilitic. Long microlites of calcic andesine are surrounded by pale-brown glass in a ratio of about 1 to 3. Sparse potassium feldspar, unidentified opaque grains, and apatite are also present in the groundmass. Most of the outcrop is considerably weathered. Calcite and limonite are abundant; phenocrysts are altered or replaced.

A porphyritic rhyodacite dike forms a conspicuous ridge about three-quarters of a mile east of Muddy Pass and a smaller separate intrusive crops out just south of the dike. The rock is light greenish gray and contains large conspicuous phenocrysts of feldspar and smaller phenocrysts of hornblende and biotite. The feldspar phenocrysts range from 1 to 10 mm in length. Microscopic examination shows phenocrysts also of feldspar, hornblende, and sparse biotite and quartz in a cryptocrystalline groundmass. The abundant large feldspar phenocrysts are oligoclase and a lesser amount of sanidine. The mafic phenocrysts are fewer and smaller and most are corroded and considerably altered to opaque grains. The groundmass is probably feldspar, quartz, and glass and lesser amounts of granular mafic minerals in clusters.

A small sill of porphyritic rhyodacite crops out in the W½ sec. 25, T. 5 N., R. 82 W. It was not examined petrographically but appears similar to the porphyritic rhyodacite described above.

Rhyodacite crops out on the eastern lower slopes of Bear Mountain as a sill, which has a maximum thickness of about 50 feet. The sill has intruded along the bedding of the enclosing Pierre Shale but has tilted the shale somewhat from its original position and has baked and discolored it from dark gray to tan. Probably it is satellite to the main intrusive mass of Bear Mountain, which is trachyandesite. The rhyodacite is a very light grayish brown and fine grained and virtually nonporphyritic, except for the presence of sparse quartz xenocrysts. It is largely altered or contaminated throughout and contains abundant limonite and calcite. Its texture is intersertal, and it consists of about equal proportions of abundant anhedral potassium feldspar and subhedral plagioclase crystals of moderate amounts of quartz and about 15 percent calcite and limonite set in a glassy matrix which makes up about one third of the rock. Identifiable plagioclase is mostly calcic andesine. Sparse biotite and unidentified opaque grains are also present.

TRACHYTE

Baker Mountain, straddling the boundary between the Rabbit Ears Peak and Lake Agnes quadrangles, is the largest body of trachyte in the area. Other outcrops include two small dikes apparently associated with the Baker Mountain intrusive.

The trachyte at Baker Mountain is medium to dark greenish gray and dense to slightly porphyritic. In thin section the rock is microporphyritic and has an intergranular to felty texture. Phenocrysts include biotite, andesine, and clinopyroxene. Some samples contain predominantly biotite; others contain no biotite. The groundmass is one-half to two-thirds feldspar, including potassium feldspar and andesine in various proportions, and much clinopyroxene. Sparse accessory minerals include quartz, biotite, possible zeolites, and apatite. Much calcite occurs in varying amounts as a secondary alteration mineral.

The trachyte at Baker Mountain was intruded for the most part concordantly into the east-dipping Benton Shale. Apparently the cross-cutting feeder for the trachyte turned and moved along the bedding after reaching a shallow depth below the surface, but it thickened in moving upward and steepened the east-dipping Benton as much as

15°. The east face of the mountain slopes about 25° to the east. Beds of baked and hardened Benton Shale lie on the east face and extend as high as the crest. Several thin layers of altered shale, intercalated with trachyte, crop out near the crest of the mountain on its west side. The west face of the mountain is a steep cliff whose lower slopes are covered by a thick talus of trachyte blocks. The maximum thickness of the trachyte unit is about 650 feet. A normal fault with at least 100 feet of throw has dropped the beds on part of the southeast side of the mountain; remnants of Benton Shale are preserved in the downdropped block, but the Benton has been stripped from the mountain north of the fault. A large area of landslides and colluvium north and west of Baker Mountain consists of very abundant material evidently derived from Baker Mountain.

Two small dikes just east of Baker Mountain are probably related to the larger intrusive.

In the normative grouping (table 4), three samples from Baker Mountain (18–20) fall into three different categories: rhyodacite, trachyte, and latite. Sample 19 probably is the most typical of the intrusive body as a whole.

A thin discontinuous trachyte sill crops out just south of Whiteley Peak Reservoir in the Lake Agnes quadrangle; its maximum thickness probably does not exceed 40 feet. The sill concordantly intrudes the gently east dipping Pierre Shale and has baked and hardened the shale for a foot or so above the contact. It is light to medium greenish gray, fine to medium grained, and porphyritic. The abundant small phenocrysts are biotite, which give the rock a sparkly appearance. In thin section the rock appears to be granular to poikilitic rather than porphyritic. Large interlocking anhedral plates of sanidine surround abundant biotite crystals that range from a length of 1 mm to a very fine grain size. The ratio of sanidine to biotite is about 3 or 4 to 1. These two minerals make up about 80 percent of the rock. Other constituents are mostly very fine grains of augite, small amounts of unidentified opaque grains, and sparse apatite.

LATITE

Intrusive bodies of latite crop out at widely scattered localities: near Doran Creek, just south of Little Haystack Mountain, southeast of Lake Agnes, and in the southwestern part of the Whiteley Peak quadrangle.

A sill more than a mile long and as much as 100 feet thick forms a crescent-shaped outcrop half a mile east of Doran Creek, mostly in sec. 2, T. 6 N., R. 82 W., and constitutes the farthest north outcrop of Tertiary igneous rock in the area. It concordantly intrudes the lower member of the east-dipping Coalmont Formation. The rock is medium brownish gray, weathers reddish brown, and is fine grained and is locally amygdaloidal. In thin section (sample 25, tables 2–4), the rock has an intersertal texture; elongate plagioclase and some potassium feldspar grains surround anhedral masses of chlorite and unidentified fine opaque grains. Plagioclase, which is mostly sodic labradorite, occurs in a ratio of about 3 to 1 to potassium feldspar, and apatite is a sparse accessory.

Just south of Little Haystack Mountain, rock of a lithology somewhat different from that of the main body of rhyolite on the mountain is classified as a latite (sample 22, tabes 2–4). It is less silicic than most of the rhyolite at Little Haystack Mountain and likely represents a separate intrusive body. It is grayish purple and porphyritic. Phenocrysts of andesine and sanidine, in a ratio of about 3 to 1, and sparse biotite, augite, and unidentified opaque grains lie in an intergranular matrix consisting of cryptocrystalline feldspar and isotropic material.

A sill of olivine latite (sample 26, tables 2–4) forms a prominent unnamed hill about a mile southeast of Lake Agnes. The enclosing rock is shale of the gently east dipping Niobrara Formation which the latite has intruded more or less concordantly. The upper surface is irregular, however, and local crosscutting is indicated. The feeder for the intruding magma may have been along or related to the fault on the east, the magma then intruding concordantly with the beds of the Niobrara and thickening in the updip direction. Thus the pattern of intrusion is similar to that of Baker Mountain, Bear Mountain, and Whiteley Peak. The maximum thickness of the sill is about 100 feet, and steep cliffs are present on the south side. A large patch of baked hardened shale that lies on the upper slopes of the hill and baked shale that extends downslope east of the latite outcrop as far as the fault on the east indicate that the intrusive body is present at a shallow depth.

The rock is dark gray to black and fine grained to dense and is seen in thin section to be slightly porphyritic and to have an intergranular groundmass. Small phenocrysts of olivine and a few of subhedral to anhedral corroded clinopyroxene, mostly augite, occur in the proportion to groundmass of 1 to 6. The groundmass minerals are fairly coarse; they are feldspar (potassium feldspar along with labradorite), which makes up about two thirds of the groundmass, anhedral biotite, olivine, and augite in roughly equal proportions, unidentified opaque grains, and sparse accessory apatite.

Several satellite sills and small dikes are present west of the main body. The ones farthest west intrude the Codell Sandstone Member of the Benton Shale in the SW¼ sec. 4, T. 4 N., R. 82 W.

A series of latite dikes and sills crops out in Muddy Creek valley in the southwestern part of the Whiteley Peak quadrangle. Most of them are intruded along, or apparently related to, a long fault that extends at least from Lindsay Creek near the Haworth Ranch southward into the Kremmling quadrangle. Dips of the intrusives range from vertical to as low as 40° east; most of the intrusives are sills that dip steeply east. Most have been intruded either along the fault or along beds that dip steeply east near the fault. Nearly vertical dikes are intruded along the fault near Lindsay Creek and at the south boundary of the area. In the intervening area, the intrusives are mostly sills. Some are compound, being composed of two to five splits. Individual splits range from 1 to 30 feet in thickness. The host rock is shale of the Niobrara Formation or of the Pierre Shale which has been baked and hardened by the intrusives along contact. East of the fault, small discontinuous sills crop out. The latite has nearly the same lithology in all outcrops. It is medium to light brownish gray and slightly porphyritic or vesicular and amygdaloidal. Most outcrops are altered and considerably weathered. Microscopic examination shows the rock to be microporphyritic with an intergranular groundmass. The most abundant phenocrysts are clinopyroxene; other phenocrysts are hornblende and biotite, in roughly equal proportions. All phenocrysts are highly corroded and altered to opaque grains. Some quartz amygdules as much as 2 mm long are also present. The groundmass is about two thirds cryptocrystalline material, which is mostly feldspar. Pyroxene, hornblende, and biotite, all highly corroded and altered to opaque grains, a little amygdaloidal quartz, and sparse apatite make up the remainder of the groundmass. The feldspar is plagioclase and potassium feldspar, in roughly equal proportions. Identifiable plagioclase is sodic andesine. Weathered rocks contain much calcite.

TRACHYANDESITE

Dikes and sills of trachyandesite are fairly abundant at localities scattered throughout the area. Bear Mountain and Diamond Mountain are the largest and most prominent of these intrusive bodies. A sill forms Harrison Hump. Several intrusive bodies crop out a mile north of Rabbit Ears Peak, and small dikes occur a mile west of North Ryder Peak, near Little Haystack Mountain, and a mile east of Dennis Hump.

Most of the trachyandesites are medium to dark greenish or brownish gray, but some are dark gray. They range from porphyritic to fine grained. Thin-section examination shows that the trachyandesites vary considerably in lithology. Textures are mostly intergranular, but some are intersertal or trachytic. Phenocrysts consist of clinopyroxene (generally augite), andesine, hornblende, and spare amygdaloidal quartz. Groundmass minerals commonly include plagioclase (sodic labradorite or andesine) and potassium feldspar and less commonly, clinopyroxene, serpentinized or chloritized pyroxene, hornblende, unidentified opaque grains, and glass. Olivine and hypersthene are present in the dikes north of Rabbit Ears Peak.

The intrusive on Harrison Hump in secs. 22 and 27, T. 6 N., R. 82 W., forms a ridge which is capped by east-dipping shale of the Niobrara Formation which has been concordantly intruded, baked, and hardened to a dark hornfelslike rock. This sill has a maximum thickness of 180 feet. A small sill cropping out just northeast of the larger sill is virtually the same type of rock. The trachyandesite is generally dark brownish gray. The texture of the main sill rock approaches that of a diabase, and at many places the rock appears to be porphyritic or coarse grained. All outcrops are much weathered.

Several bodies of trachyandesite crop out within the great mass of surficial rubble about a mile north of Rabbit Ears Peak. The large amount of rubble, consisting mostly of large blocks of trachybasalt, nearly covers the outcrops and makes their relationship to the surrounding rocks very obscure. However, they are probably instrusive bodies. The trachyandesite is mottled medium to dark brownish or greenish gray; it is fine grained and slightly porphyritic. Visible phenocrysts are altered olivine.

Diamond Mountain is a small but prominent flat-topped hill on the Continental Divide in the southeast corner of the Rabbit Ears Peak quadrangle. It is formed by an irregularly shaped body of trachyandesite intruded at a fairly high angle into the lower member of the Coalmont Formation. Intrusive contacts are exposed on the northwest and northeast sides of the hill. On the northwest side, altered Coalmont sandstone and sparse intrusive breccia mark the contact. On the northeast side, the contact is marked by baked and hardened Coalmont shale. A long narrow basanite dike trends northwest across the mountain. The rock is fine grained, nonporphyritic, and medium to dark greenish or brownish gray. It tends to weather pale reddish brown and forms steep cliffs characterized by columnar jointing. Most of the small trachyandesite dikes northwest of Diamond Mountain are similar to the rock on Diamond Mountain.

Bear Mountain, which lies along the Continental Divide, is one of the most prominent hills in the area, and is the largest body of intrusive trachyandesite. Its crest stands 1,500 feet above the valley of Muddy Creek, and the intrusive rock of the mountain forms cliffs as much as 650 feet high. Several satellite sills crop out east and south of the main intrusion. The intrusive at Bear Mountain is a large irregularly shaped crosscutting body, but like Whiteley Peak and Baker Mountain appears to have been intruded at least in part concordantly with the structure of the enclosing Pierre Shale. The mountain has a slope of 15°–20° on its northeast side and is in sharp contrast to the precipitous cliffs on its southwest side, which suggests that the body moved roughly in accord with the east-dipping regional structure but expanded abruptly in its upward movement. An outcrop at the north edge of the intrusive body exposes the contact of the trachyandesite with the Pierre Shale. The Pierre overlies the intrusive and is baked by it to a hard brittle hornfelslike rock. None of this type of rock was seen, however, on the higher slopes. The lowermost and largest of the three sills south of Bear Mountain forms a fairly flat topped terrace several acres in extent, much of which is capped by baked and hardened Pierre Shale.

The trachyandesite of Bear Mountain is fine grained, nonporphyritic, and mostly medium to dark greenish gray. Resistant cliffs show good columnar jointing and tend to weather brownish red. In places, however, the rock weathers to produce a greenish-gray sandy surface wash.

The rock of the dikes satellite to Bear Mountain is nearly the same as that of the main body; it is medium gray, fine grained, almost dense, and nonporphyritic. The largest of the satellite sills has a maximum thickness of about 75 feet.

The small dikes along the boundary of secs. 35 and 36, T. 5 N., R. 82 W., were not studied petrographically, but appear to be generally similar to the other trachyandesites of Bear Mountain.

About half a mile west of Little Haystack Mountain (Spicer Peak quadrangle) are two small knobs that protrude above the mass of landslide rubble. Their true relationship to the surrounding rocks is unknown, but they are interpreted to be intrusive bodies. Both units are porphyritic trachyandesite, but they are not only dissimilar to each other but are dissimilar to other intrusive trachyandesites elsewhere in the area. The eastern knob is composed of a medium-gray to brown-mottled porphyritic rock, which weathers to a rough reddish-brown surface. The western knob is a dark-gray porphyritic rock.

Two small dikes crop out about a mile west of Dennis Hump. The rocks were not studied in detail, but they are medium gray to purplish gray and slightly porphyritic and appear to be elongate intrusive bodies.

Two long narrow northwest-trending dikes crop out about a mile west of North Ryder Peak. These dikes intrude the Coalmont Formation; they are approximately in line with each other and also are in rough alinement with South Ryder Peak, which is a trachybasalt intrusive. The dike rock, however, is medium to dark gray and porphyritic and is classified as trachyandesite rather than trachybasalt.

TRACHYBASALT

Intrusive bodies of trachybasalt, including dikes, plugs, and sills, are fairly abundant and widespread through the southern two-thirds of the area. Major intrusive bodies include those at Rabbit Ears Peak, a hill 1 mile east of Muddy Pass, Spicer Peak, Ironclad Mountain, and North and South Ryder Peaks. Small dikes are present at other scattered localities. Nearly all the intrusive trachybasalts are very dark gray or black rocks that contain olivine, clinopyroxene, and labradorite. Most are dense to slightly porphyritic.

In thin section most of the trachybasalts contain phenocrysts of olivine and clinopyroxene (mostly augite), and less commonly labradorite, in a groundmass of intergranular texture. A few of the trachybasalts have a hyalopilitic or felty texture. Groundmass minerals are mostly labradorite, and olivine, clinopyroxene, and opaque iron ore grains are common; less common are potassium feldspar, biotite, and glass. Sparse quartz, apatite, and zeolites may also be present. The olivine in many samples is altered to serpentine or antigorite.

A plug of trachybasalt forms a volcanic center just west of Rabbit Ears Peak. Mudflow and pyroclastic breccia, ash, and lava flows in the vicinity are associated with the plug. This plug is one of the few intrusive bodies in the area which is clearly a volcanic center, as demonstrated by its association with nearby eruptive rocks, but its occurrence suggests that numerous similar intrusions in the area, which do not now have associated eruptive rocks, may also have been volcanic centers. The plug apparently is a steeply crosscutting body of irregular shape but is generally elongate in a northwesterly direction. It intrudes mostly the lower member of the Coalmont Formation, although surficial debris obscures the contact between the units. The rock is hard and resistant, mostly dark gray to black, and fine grained to dense; it is virtually nonporphyritic except that small crystals of olivine are visible under a hand lens. Locally the rock is slightly vesicular.

An apparent satellite dike is present just west of the main plug of the Rabbit Ears Peak area. This dike, which is not mapped separately, served as a feeder for the extensive trachybasalt flow to the west. The dike rock is virtually identical to the trachybasalt of the plug except that it contains sparse vesicle fillings of quartz and calcite.

Two small trachybasalt dikes crop out about 2½ miles northeast of Rabbit Ears Peak. Both dikes intrude the lower member of the Coalmont Formation. The more southern dike forms a small prominent knob and has a well-exposed intrusive contact with shale of the Coalmont, which is baked and hardened at the contact. This dike strikes northwestward and dips steeply to the northeast. The rock is almost identical to the trachybasalt near Rabbit Ears Peak.

About a mile north of the mouth of Wilset Creek in the east-central part of the Rabbit Ears Peak quadrangle are several small northwesterly alined dikes and apparent plugs. Breccia is associated with two of these intrusives, which likely represent a small eruptive center. The rock is dark brownish gray to black and dense to slightly porphyritic; the visible phenocrysts are mostly pyroxene. One sample (no. 49, tables 2–4) is chemically one of the most mafic of all the Tertiary igneous rocks in the area, having only 46 percent silica.

Two fairly extensive bodies of trachybasalt crop out about a mile east of Muddy Pass in secs. 23, 24, and 25, T. 5 N., R. 82 W. They cap the upper slopes of a heavily timbered hill and are obscured by timber and surficial rubble except at their south end. Their true mode of occurrence is equivocal. They are not capped by baked shale as are other sills in the area, and they may be flows rather than sills. They do not have the vesicular texture of other trachybasalt flows, however, and their even, northeastward slope suggests intrusion more or less concordantly with the gently eastdipping Pierre Shale. They form thin tabular units, and the maximum thickness probably does not exceed 40 feet. The rock is nearly black, fine grained, and almost dense to slightly porphyritic.

Several thin trachybasalt dikes and sills crop out north and east of Bear Mountain. The only one of these studied in detail is the sill just north of the outcrop of trachyandesite of Bear Mountain. It is nearly black, medium to fine grained, and slightly porphyritic.

Several very small northeasterly trending dikes intrude breccia in a ridge about 1 mile northeast of the F. P. Murphy Ranch in the northwestern part of the Spicer Peak quadrangle. Apparently the small dikes were intruded into the breccia because altered breccia occurs along the contact. The trachybasalt is black and dense. The entire breccia-dike unit probably represents the site of a small eruptive center.

Spicer Peak is a prominent cone-shaped hill in the east-central part of the Spicer Peak quadrangle. The hill stands 1,200 feet above the valley of Arapaho Creek, but only the top 200 feet or so is composed of trachybasalt. The peak is roughly circular in outcrop and is very likely a plug although no extrusive rocks are present nearby. The slopes of the mountain, however, are littered with abundant blocks of trachybasalt which may represent the remnants of a flow. The contact with the Coalmont Formation is covered by a talus from the steep cliffs of the peak. The trachybasalt is black, nearly dense, hard, and resistant.

Ironclad Mountain is a low but prominent hill in the south-central part of the Spicer Peak quadrangle. The northern part of the trachybasalt, as shown on the geologic map (pl. 2), is largely an area of abundant surficial rubble and only scattered knobs of trachybasalt. Grout (in Grout and others, 1913, p. 44) interpreted Ironclad Mountain as a laccolith, but there is no clear evidence for this interpretation, inasmuch as contacts with enclosing strata are lacking. Outcrops like those at the northwest end of the mountain resemble a dike. A patch of conglomeratic sandstone of the Coalmont Formation caps the trachybasalt at the south end of the mountain, however, and it is likely that the intrusive unit is laccolithic or perhaps is a thickened sill similar in mode of intrusion to Bear Mountain or Whiteley Peak. The rock is dense and dark gray to black and weathers red.

Several small dikes crop out northwest of Ironclad Mountain, mostly in sec. 3, T. 5 N., R. 81 W. Three of these are exposed on the south bank of Grizzly Creek. They range from dark greenish gray porphyritic rocks to black dense nonporphyritic rocks. They were not studied in detail and are arbitrarily mapped as trachybasalts. Two small intrusive bodies of dark dense to porphyritic rock crop out southwest of Ironclad Mountain, in secs. 10 and 16, T. 5 N., R. 81 W.

Igneous bodies on North and South Ryder Peaks in the northern part of the Whiteley Peak quadrangle and in a northwest-striking vertical dike about a mile northwest of North Ryder Peak are trachybasalts intruded into the Coalmont Formation. North Ryder Peak is a plug and is associated with Breccia. (See discussion of Breccia, p. 62). South Ryder Peak is similar to North Ryder Peak and may also be a plug. The north wall of South Ryder Peak forms a nearly sheer cliff 150 feet high. Both are elongate and trend northwestward and are steeply crosscutting. The dike northwest of North Ryder Peak thins and splits into three thin dikes toward its northwest end. The rocks were not studied petrographically, but they are apparently the same as olivine-bearing trachybasalts seen elsewhere in the area. They are black, fine grained to dense, and mostly nonporphyritic.

Trachybasalt intrudes the Pierre Shale and probably some of the lower units of breccia of the Rabbit Ears Volcanics just southwest of White Slide Mountain in sec. 7, T. 4 N., R. 80 W. (fig. 6). Abundant breccias, particularly the red breccias near the plug, contain considerable scoria and bombs probably derived from the eruptive center now represented by the intrusive unit. The rock is black and weathers purplish brown; it is fine grained to dense and is irregularly porphyritic.

Numerous small dikes and sills crop out in the southern part of the area. Only a few of these were studied in detail, but all are dark gray to black and resemble trachybasalts elsewhere in the area.

A prominent northeast-sloping synclinal hill in sec. 5, T. 3 N., R. 81 W. (Whiteley Peak quadrangle), is underlain by a sill which crops out around the upper margins of the hill. The sill intrudes and has baked and hardened the enclosing shale of the Niobrara Formation. Its maximum thickness is about 50 feet on the west side of the hill. Just north of this hill, on the north bank of Hill Creek, are several very thin discontinuous intrusives, some of which are crosscutting, whereas others are concordant. These intrusives are probably related

FIGURE 6.—Trachybasalt intrusive (center foreground) at edge of breccia pile of Rabbit Ears Volcanics, some of which is seen at left background; summit of White Slide Mountain at upper left. East ½ sec. 7, T. 4 N., R. 80 W.

to the larger sill. The rock is mostly dark gray to black, dense, and nonporphyritic, but it is locally porphyritic.

About 2 miles northwest of Hill Creek, in sec. 30, T. 4 N., R. 81 W., three vertical northwest-striking dikes crop out, roughly in a line. The rock is virtually identical to the trachybasalt in the sill south of Hill Creek.

Several very small trachybasalt dikes crop out between Indian Pass and Eastern Gulch in the south-central part of the Whiteley Peak quadrangle. These nearly vertical dikes intrude the Pierre Shale. The most northern dike is about 20 feet thick; the others are thinner. The rock is dark gray to black, fine to medium grained, and speckled by plagioclase crystals; it weathers brown.

Two intrusives, the first half a mile southeast of Carter Mountain and the other a mile south of Parsons Reservoir in the southeastern part of the Whiteley Peak quadrangle, appear to be trachybasalt similar to that farther west. The rock is dark gray to black and mostly dense. The mode of occurrence of the two bodies is obscure owing to partial cover by heavy surficial rubble, but both intrusives are probably dikes.

A trachybasalt dike, only a few feet wide, crops out near the northeast corner of the Rabbit Ears Peak quadrangle, where it intrudes gently northeast-dipping beds of the lower member of the Coalmont Formation. It dips steeply eastward and may be intruded along a fault, as its northwest strike parallels that of a steeply east-dipping normal fault less than half a mile to the northeast. The rock is black and fine grained to dense.

BASANITE

A northwest-striking nearly vertical basanite dike cuts across Diamond Mountain. Its maximum width is about 8 feet. The rock is dark gray to black and is mostly porphyritic. The phenocrysts are pyroxene, as much as 1 cm long, and altered olivine, which are smaller. As seen in thin section, large phenocrysts of euhedral augite as much as 3 mm long and olivine altered to serpentine or calcite, also as much as 3 mm in length, lie in a fine-grained groundmass, which is about half clear to brown weakly birefringent material, probably chlorite, glass, zeolites, and cryptocrystalline feldspar. The rest of the groundmass consists of clinopyroxene, unidentified opaque grains, some microlitic plagioclase, and sparse biotite.

AGE AND CORRELATION

The age of the Tertiary igneous rocks is not precisely known, but it probably ranges from Oligocene to late Miocene or possibly Pliocene. West of Rabbit Ears Peak, outside the mapped area, flows of trachybasalt enclose limestone typical of that of the North Park Formation of late Miocene age, and rubble of this or similar flow rock elsewhere overlies ashy limestone rubble of the North Park, or possibly the Troublesome Formation of Miocene age. Thus, the youngest flows and related intrusives must be no older than late Miocene and possibly are as young as Pliocene. D. M. Kinney (oral commun., 1965) has mapped flows and other volcanic rocks interfingering with ashy beds of the North Park Formation on Owl Mountain in southeastern North Park. In the Hot Sulphur Springs quadrangle, Izett (1966) has shown that the Grouse Mountain Basalt, dated as Pliocene (?), unconformably overlies the Troublesome Formation of late early and late Miocene age. The Grouse Mountain Basalt may be equivalent to some of the younger flows in the mapped area.

The lower age limit of the Tertiary igneous rocks is not clearly known. Although many of these igneous rocks intrude or unconformably overlie rocks of the Coalmont Formation of Paleocene and Eocene age, others intrude rocks of Late Cretaceous age; nevertheless, many of these are sills intruded concordantly at shallow depth into tilted strata whose structure is dated as Laramide, which in this area is no older than Paleocene. Izett (1966) showed that the Rabbit Ears Volcanics underlie the Troublesome Formation of Miocene age in the Hot Sulphur Springs quadrangle and that a sample from about the middle of the Rabbit Ears, dated by the potassium-argon method, is about 33 million years old, or Oligocene in age. Izett also pointed out that locally the Rabbit Ears Volcanics seem to grade upward into the Troublesome Formation of Miocene age, and suggested that the Rabbit Ears Volcanics might be in part early Miocene(?) in age. Tweto (1957, p. 24) postulated that the volcanic center of Green Mountain in central Middle Park, about 25 miles south of the mapped area, is post-middle Tertiary, possibly Pliocene, in age. Tweto pointed out the similarity of the trachytes of Green Mountain to some of the rocks in the Rabbit Ears Range, and suggested a probable middle or late Tertiary age. Bass and Northrop (1963, p. J61–J62) mapped basalt flows in the Flat Top area, about 40 miles southwest of southwestern North Park, and designated their age as Miocene(?) to Pleistocene.

SURFICIAL DEPOSITS—QUATERNARY

PLEISTOCENE SERIES

Pleistocene deposits in the area include till of three glaciations, outwash, terrace gravels, pediment gravels, and block slides. Outwash and glaciofluvial terrace gravel of the two younger glaciations are correlative with till of mountain valley glaciers. Older terrace gravels may be partly of glaciofluvial origin but cannot be correlated with older till deposits.

For convenience in mapping and discussion, the deposits of the three glaciations are numbered from oldest to youngest, 1, 2, and 3. Drift of glaciation 1 includes only till. Drift of glaciations 2 and 3 includes till, outwash, and parts of terrace gravels, some of which are of glaciofluvial origin. The unit designated "glacial till" is of questionable glacial origin and no attempt was made to correlate it with the other glacial deposits. The correlation of glacial deposits follows the suggested correlation for northwestern North Park (Hail, 1965, table 1, p. 88).

DRIFT OF GLACIATION 1

A small outcrop of glacial till of probable pre-Wisconsin age caps an interstream upland just north of Beaver Creek in the northwest corner of the area. The till has no morainal form, is nowhere well exposed, and supports a dense growth of evergreens. The till is apparently highly weathered and contains boulders, few of which exceed 5 feet in length, which have been rounded by weathering. Many of the boulders are so thoroughly weathered that they crumble easily. The deposit is relatively thin and rests on weathered Precambrian quartz monzonite. The antiquity of the till is demonstrated by its position high on a divide bordered by steep cliffs as much as 1,000 feet high which were cut after deposition of the till.

OLDER TERRACE GRAVELS

In North Park (Atlantic drainage north of the Continental Divide), five distinct terrace levels can be recognized. The upper three of these are rock-cut stream terraces mantled by thin deposits of weathered gravel. These three gravels are designated older terrace gravels. The lower two terraces are covered by gravel which is in part glaciofluvial in origin and which is correlative with glaciations 2 and 3. The relative age of the older gravel is based mainly on the relative topographic position of the terraces on which they lie. The lowest of the three older terraces generally lies 10–25 feet above the terrace correlated with glaciation 2 in downstream areas, and 30–60 feet above the terrace in upstream areas. The middle terrace generally lies 40–60 feet above the lower terrace. The highest older terrace lies 60–80 feet above the middle terrace. Sublevels are present locally, and distinction between the main terrace levels is difficult.

Lithologically the three older terrace gravels are similar, and they consist of probable stream-laid material ranging in size from sand to boulders as much as 1½ feet in length. Two distinct lithologies are represented: granitic and volcanic. These materials clearly were derived from two different source areas, the Park Range to the west for the Precambrian granitic material and the Rabbit Ears Range to the south for the Tertiary volcanic material. The older terrace gravels in the Beaver Creek, Morey Draw, upper Chedsey Creek, and upper Little Grizzly Creek drainages are composed almost entirely of Precambrian granitic detritus. In the area south and east of Little Grizzly Creek, the older terrace gravels are composed almost entirely of volcanic rock detritus. Here, crystalline material does not exceed 10 percent, and this may have been derived from reworking of arkosic rocks of the Coalmont Formation.

The extensive outcrop of the youngest of the older gravels, lying about 1½ miles northwest of Little Grizzly Creek, contains a mixture of granitic and volcanic constituents in roughly equal proporations. This demonstrates at least a 4-mile eastward migration of the course of Grizzly Creek since this gravel was deposited.

The granitic gravel ranges in thickness from a few inches to as much as 25 feet. Cobbles and boulders are subangular to well rounded; the sand fraction is mostly angular. Much of the gravel is highly weathered and decomposed. The gravel is irregularly cemented by calcium carbonate, limonite, or clay. A small amount of the gravel was derived from hard sandstone of the Dakota Sandstone. Locally a thin soil zone is developed on the gravel. Where a well-developed soil zone is absent, in many places an A horizon of dark-brown loamy sand, and commonly caliche or powdery white calcium carbonate, are present.

Volcanic gravel consists of diverse types such as trachybasalt, breccia, quartz latite, porphyry, and others, but dark dense rocks, mostly trachybasalt, predominate. The gravel has a maximum thickness of about 16 feet. Most of the cobbles and boulders are subangular and only silghtly weathered, in contrast to the highly weathered rocks of the granitic gravels. Sorting is generally poor. The proportion of gravel to sand is higher in the volcanic gravel than in the granitic gravel. A well-developed soil zone is generally absent but an A horizon is present locally, and calcium carbonate, which provides a good cement for much of the gravel, is fairly abundant at most places.

The lithology and fabric of those older terrace gravels composed of granitic constituents are similar to those of younger glaciofluvial gravels, but none of the older gravels can be definitely correlated with known deposits of glacial drift.

GLACIAL TILL(?)

Several masses of bouldery gravel are present in the southwest corner of the Lake Agnes quadrangle. They lie mostly on Precambrian quartz monzonite, but the largest mass lies on rocks as young as the Dakota Sandstone. These gravels closely resemble glacial till, but the glacial origin is questionable because no obvious cirque source is seen in the nearby hills of the Park Range. They apparently consist of unsorted boulders and cobbles of pink medium-grained granitic rocks, as much as 3 feet in length. Many are soled, grooved, and faceted.

PEDIMENT GRAVELS

In the southern part of the area, several small isolated pediments of evenly sloping ground are capped by rubble chiefly composed of volcanic igneous rock and minor sandstone. The material appears to be unsorted and contains angular cobbles and boulders, a few of which are 3 feet long. The source of the volcanic material in the pediment gravels east of Muddy Creek was probably the Rabbit Ears Volcanics or local intrusive bodies such as at Whiteley Peak. Pediment gravel west of Muddy Creek, in addition to the volcanics, also includes some sandstone from the Dakota Sandstone and from the Codell Sandstone Member of the Benton Shale. The topographic position of the pediments, standing as prominent interstream divides, shows that the pediments were formed prior to the development of recent drainage patterns, and the gravels are therefore regarded as Pleistocene in age.

STREAM TERRACE DEPOSITS

In the southern part of the area, several terraces, clearly related to the main valley trunk stream, Muddy Creek, are capped by alluvial gravels. In the area upstream from the DeBerard Peak Ranch, the gravel is composed of sandstone of the Dakota Sandstone, volcanic rock, and less granitic rock in decreasing order of abundance. Apparently a considerable proportion of the volcanic rock is an admixture of locally derived hillwash rubble. The sandstone boulders and cobbles are mostly subrounded. Few exceed 10 inches in length. Locally derived volcanic rock material includes angular boulders as much as 4 feet in length. The Dakota Sandstone constituents doubtless were derived from the Dakota outcrop 2–3 miles to the west. The gravel probably does not exceed 10 feet in thickness.

Terraces along Muddy Creek between the Ritschard Ranch and the south boundary of the area are capped by gravel composed almost entirely of volcanic rock and by much sand. A considerable proportion of the gravel on these terraces is locally derived hillwash rubble and consists of boulders as much as 4 feet long. Most of the gravelly material is subrounded to rounded cobbles, generally not exceeding 7 inches in length. The gravel in this area ranges in thickness from a few inches to about 20 feet.

The terraces occupy at least two levels above Muddy Creek—the lower about 80–120 feet above stream level and the upper about 200 feet above stream level. The terrace levels are not differentiated from each other on the geologic map.

TILL OF GLACIATION 2 AND RELATED GRAVELS

Deposits of till, outwash, and glaciofluvial stream terrace gravel are related to the older of two major glaciations of Wisconsin age. Certain of these stream terrace gravels in the northeastern part of the area are in part glacial and in part nonglacial in origin.

Glaciers of both major glaciations of Wisconsin age in the mapped area were approximately coextensive and were confined mainly to stream valleys on the east flank of the Park Range. Large areas of drift of glaciation 2 were doubtless either destroyed by younger glaciers or covered by their deposits.

Exposures of till and outwash of glaciation 2 are scattered along the Park Range flank mostly in the northwest corner of the area, adjacent to drift of the younger glaciation 3. Another small patch of till and outwash is present near Rabbit Ears Pass in the southwest corner of the Rabbit Ears Peak quadrangle. A large patch of glaciofluvial terrace gravel occupies part of the low nearly flat divide between Chedsey and Little Grizzly Creeks. Nonglacial and mixed glacial and nonglacial terrace gravels cover extensive lowland areas in the lower valleys of Grizzly and Little Grizzly Creeks. Smaller scattered exposures of these gravels are present elsewhere in the northern and eastern parts of the area.

Till of glaciation 2 composes moraines, which have a conspicuous morainal topography but one that is fairly gentle and subdued, owing to a long period of postglacial weathering and erosion. Bouldery hummocks are locally present but are inconspicuous. Glacial lakes, swamps, and undrained depressions are uncommon. Surface boulders as much as 8 feet long are present, but they are not abundant. Terminal ridges are inconspicuous, and are well trenched by postglaciation 2 streams.

Typical glaciation 2 till is exposed in the terminal moraine of Newcomb Creek in the SE¼ sec. 11, T. 7 N., R. 82 W., and has been described in a previous report (Hail, 1965, p. 91–92). It consists of unsorted granitic bouldery material. Decomposition of the constituent material is far advanced. All the moraines are composed of granitic material except the moraine at Rabbit Ears Pass, which is composed of mixed granitic and volcanic material.

Outwash gravels compose fans adjacent to moraines, and grade into the glaciofluvial terrace gravels. No distinction is made on the geologic map between outwash and correlative terrace gravels. The surface of the outwash has a relatively steep gradient near its contact with the moraine, where it is bouldery and very poorly sorted. The sorting becomes better and boulder size decreases abruptly as the outwash grades into the glaciofluvial terrace gravels.

The terrace gravels are of three types: glaciofluvial gravels of granitic-rock composition, nonglacial gravels of volcanic-rock composition, and a mixture of these two. The terrace gravels range in thickness from a few feet to about 20 feet. They lie from about 20–30 feet above present streams in downstream areas to as much as 60 feet in upstream areas. Few outcrops of glaciation 2 gravels lie adjacent to outcrops of the younger glaciation 3 gravels, but differences in elevation between them range from as little as 5 feet downstream to as much as 50 feet upstream.

The glaciofluvial gravels composed largely of granitic material had as their major source the moraines flanking the Park Range. These gravels are present in the drainage areas of Beaver Creek, Chedsey Creek, Little Grizzly Creek above the mouth of Chedsey Creek, and along upper Muddy Creek near Rabbit Ears Pass. Gravel of this type is composed almost entirely of granitic material, but it also contains a small amount of sandstone from the Dakota Sandstone. It is typically alluvial and consists of a coarse sand matrix and varying amounts of pebbles, cobbles, and a few boulders less than 1 foot long. The gravelly constitutents are mostly rounded or subrounded. Bedding is indistinct except in some sand lenses. Weathering and decomposition of the gravel are moderate to considerable.

Nonglacial terrace gravels of volcanic rock composition were derived from the Rabbit Ears Range to the south. These gravels are present mainly in the Grizzly Creek drainage roughly to the south of Hebron. They are composed of various Tertiary volcanic rock types but are mostly dark basaltlike rocks. The fabric of these gravels is much like that of the granitic gravel except that these gravels are considerably less weathered and decomposed.

The mixed glacial and nonglacial gravels occupy the area adjacent to Grizzly and Little Grizzly Creeks, roughly to the north of Hebron, and northeast from the mouth of Chedsey Creek. Gravel east of Little Grizzly Creek is predominantly volcanic. Mixing of the gravels apparently occurs in two ways: a random mixing of the two types and an interfingering of distinct units of the two types.

TILL OF GLACIATION 3 AND RELATED GRAVELS

The younger of the two major glaciations of Wisconsin age, like the older, is represented by deposits of till, outwash, and glaciofluvial terrace gravels. A large mass of surficial material southeast of Rabbit Ears Peak is probably mixed till and landslide material. Some of the material mapped as till northward from Rabbit Ears Peak to Colorado Creek may also include landslide or other surficial material. Certain minor stream terraces along Grizzly Creek are correlative with glaciofluvial stream terrace gravels elsewhere, but are themselves nonglacial in origin.

Glacial till and mixed till and landslide material are present along the Park Range flank, and these make up the greatest proportion of deposits related to glaciation 3. A large patch of till occurs in the northwestern part of the Teal Lake quadrangle, which occupies the upper valleys of Beaver, Whalen, Newcomb, and Chedsey Creeks. Probable glacial lake deposits form part of the floor of Newcomb Park; these were not mapped separately. Each of the four stream valleys were channels for separate glaciers. The glaciers of Beaver, Newcomb, and Chedsey Creeks, the largest of which was the Newcomb, coalesced at their lower margins to deposit a continuous compound mass of lateral and terminal ridges. The younger moraines in this area did not reach as far basinward as the older moraines of glaciation 2, their outer margins lying behind the older moraines.

Moraine of glaciation 3 is present in the valley of Sawmill Creek between Little Grizzly and Crosby Creeks along the west boundary of the Teal Lake quadrangle. The till of this moraine apparently was derived from many nearby sources on the Park Range flank. Apparently the glacier was too thin to override the Dakota hogback in this area, and most of it moved northward along the valley of Sawmill Creek.

Farther to the south, between Crosby Creek and Colorado Creek, thin glaciers spread till down the valley of Colorado Creek to the vicinity of Harrison Hump. Atwood (1937, p. 131 and fig. 9) called these the Cloverleaf glacier, and showed its margin as the farthest south moraine in the lowlands of the Park Range flank.

All the glacial till north of Colorado Creek is composed of Precambrian granitic material. South of Colorado Creek and north of Rabbit Ears Peak a large mass of surficial material is considered to be in large part glacial till consisting of thick disordered bouldery masses, although probably containing much landslide debris. Most of the bouldery material is trachybasaltic debris, derived from the flows near Rabbit Ears Peak. The till heads in two steep-sided cirques on the north side of the high ground west of Rabbit Ears Peak. Landslides composing part of the unit in this area are probably due to the steep slope and nonresistant nature of the underlying sedimentary rocks which range from the Morrison Formation to the lower member of the Pierre Shale.

The large mass of surficial material southeast of Rabbit Ears Peak is considered to be a mixture of till and landslide material. It is probably similar to the till north of Rabbit Ears Peak, but is generally thin and has less morainal topography. Bouldery material is mostly trachybasaltic although many of the smaller cobbles and boulders are granitic; they were derived from the Coalmont Formation. A steep slope and an underlying shaly terrane of the Benton and Niobrara Formations probably account for the abundance of landslide material. The unit heads in the cirque just west of Rabbit Ears Peak.

A very small patch of moraine of glaciation 3 is present just northwest of old Rabbit Ears Pass. This is part of a thin but well-formed terminal moraine loop, formed by a glacier that headed in a cirque at the head of Muddy Creek just west of the mapped area. The cirque wall is capped by trachybasalt flows overlying bouldery beds of the Coalmont Formation, red beds of the Chugwater Formation, and Precambrian granitic rock. The till, which may be seen where old U.S. Highway 40 crosses it, consists of a mixture of granitic and trachybasaltic boulders, and much red shale or siltstone debris. Atwood (1937, p. 130–131) applied the name Rabbit Ears glacier to the glacier forming this moraine, and stated that it marks the south limit of Wisconsin ice in the Park Range.

A fresh disordered topography is generally formed on the till of glaciation 3, particularly that of the terminal moraines, in contrast to the more subdued topography of the till of glaciation 2. Bouldery hummocks are abundant. Numerous large unweathered boulders litter the surface. Abundant undrained depressions contain lakes or swamps. Terminal and lateral ridges are sharp and well defined, particularly in the area north of Colorado Creek. Old drainage channels, well established through moraines of glaciation 2, were obliterated by the younger moraine, and new drainage channels are poorly established; trenching through terminal loops is not well formed.

The till is typically nonsorted bouldery material containing a large proportion of clayey coarse sand. Where it is composed of granitic constituents, these are moderately weathered and decomposed, but they are relatively fresh in comparison with those of the till of glaciation 2. Trachybasaltic material shows very little weathering. The larger boulders within the till are as much as 4 feet long; boulders on the surface are as much as 20 feet or so in length.

Outwash fan and valley train gravels lie adjacent to morainal till. These gravels are similar to the outwash of glaciation 2, except that perhaps they are less weathered. Exposures are very poor owing to the lack of postglacial trenching. Coarser material is found closer to the margin of the moraines. Sorting is very poor but becomes better as the material grades basinward to glaciofluvial terrace gravels. Fan and valley train deposits occupy fairly extensive areas, whereas correlative downstream terrace gravel deposits are sparse. The upper reaches of the South Fork of Beaver Creek, Chedsey, Little Grizzly, Crosby, and Colorado Creeks all have extensive glacial outwash valley trains.

A single patch of glaciofluvial terrace gravel of glaciation 3 crops out along the south bank of Little Grizzly Creek in the northeast part of the Teal Lake quadrangle. The gravel is composed entirely of of granitic material, and probably does not exceed 15 feet in thickness. Three patches of stream terrace gravels crop out along Grizzly Creek in the northeastern part of the Coalmont quadrangle. These are nonglacial gravels composed almost entirely of volcanic rock material; they are correlated with gravels of glaciation 3 on the basis of like topographic position of their upper surfaces relative to the adjacent stream. These terrace gravels probably do not exceed 20 feet in thickness. All the stream gravels are similar to those related to glaciation 2.

There has been little or no postglacial cutting of outwash or related stream gravels of glaciation 3. In places, Recent alluvium overlies the gravel with no apparent topographic break.

BLOCK SLIDES

Several prominent block slides that range in size from about ½ to about 2½ square miles occur near the west margin of the area. They consist of resistant rock formed mostly of the Dakota Sandstone and partly of the Codell Sandstone Member of the Benton Shale, the Fort Hays Limestone Member of the Niobrara Formation, and to a lesser degree some other units. All the block slides were originally east-dipping bedrocks which moved downward largely as a mass on glide surfaces heading in nonresistant underlying shale. On the geologic map, bedrock formations are identified within each slide block where possible. Some rubbly material adjacent to the blocks is included with them.

The northernmost slide block is in the Hidden Lakes area near the west boundary of the Teal Lake and Rabbit Ears quadrangles. There a block composed mostly of the Dakota Sandstone and also some rocks of the Morrison Formation has moved downslope about 1,500 feet. The upper margin of the glide surface formed in nonresistant shale at or near the top of the Morrison Formation; the foot of the glide surface formed in the lower part of the Benton Shale. The toe of the slide consists of a pile of chaotic blocks of Dakota Sandstone that form a series of poorly drained or closed depressions which contain the Hidden Lakes.

The slide block at Lake Agnes in the northwest corner of the Lake Agnes quadrangle is similar in most respects to the Hidden Lakes slide block. A large block of Dakota has moved about 1,500 feet on a glide surface whose upper margin lies approximately at the Dakota-Morrison contact, and whose foot probably lies within the Benton Shale. The toe of the slide includes material from the Dakota and Benton Formations. Chaotic rubble in the toe of the slide forms a ridge as much at 150 feet high and impounds Lake Agnes in the resulting closed depression. Lily Lake lies in poorly drained ground behind the head of the slide. Scott (1962) described and presented a mechanical analysis of this slide.

Another large slide block, about 3 miles south of the Lake Agnes slide and just south of Muddy Creek, involves not only the Dakota but also large parts of the Morrison Formation and the Mowry Shale Member of the Benton Shale. The upper margin of the glide surface lies within the upper part of the Morrison Formation, the foot probably lies within the middle shaly member of the Benton Shale, at its stratigraphically highest point. Shales of the Morrison Formation are exposed at the east margin of the slide block and are in contact with the Benton Shale. The toe of the slide has a ridge as much as 90 feet high, but undrained depressions which characterize the slide blocks of Hidden Lakes and Lake Agnes are lacking because of drainage by a small tributary of Milk Creek. The south margin of this slide is a flexure rather than a break. Most of the eastward movement took place at the north end of the slide. The distance of this eastward movement is conjectural, but it may be on the order of 2,000 feet. Several small lakes fill undrained depressions in the landslide area above the head of the slide.

Two block slides near the south-central boundary of the Lake Agnes quadrangle are similar in form to the others, but consist mainly of the resistant Codell Sandstone Member of the Benton Shale and the basal Fort Hays Limestone Member of the Niobrara Formation. The northernmost of the two slides lies on a glide surface, the upper margin of which is in the upper part of the middle shaly member of the Benton and the foot of which is probably just above the Fort Hays Limestone Member of the Niobrara. There is no ridge at the toe of this slide. The amount of downslope movement is not known, but it may be as much as 800 feet. The southernmost of the two slides lies mostly on a glide surface very nearly at the contact between the middle shaly member of the Benton Shale and the Codell Sandstone Member; it probably cuts upward through the Codell and Fort Hays at its foot. Blocks of Codell and Fort Hays and shale of the Smoky Hill Shale Member of the Niobrara Formation form a ridge at the toe of the slide and impound Albert Reservoir in the resulting nearly closed depression. This slide has moved eastward from 500 to 900 feet.

The mechanisms causing the block slides are conjectural. The slides have several obvious features in common. All involve mainly resistant rocks lying on nonresistant shales in which the original glide surface formed. All were originally parts of dip slopes which probably dipped 8°–15° to the east. It is evident that joints, faults, or other zones of weakness at the foot of the slide gave rise to the initial fracturing that permitted the slide to break loose and begin its downward and outward movement. Scott (1962, p. 36–39) in his mechanical analysis of the Lake Agnes landslide suggested that water saturation of the Dakota together with fracturing would have been enough to destroy the equilibrium of the block to initiate sliding. Inasmuch as the foot of all the slides is covered, the true nature of the fracturing is unknown. A small fault passes beneath the Hidden Lakes slide, but faults are apparently absent in the other slide areas. Similar slides are present in the Gore Pass quadrangle to the south and in the Kremmling quadrangle to the southeast.

The block-slide deposits are dated as late Pleistocene. The slide deposit at Hidden Lakes is probably slightly younger than, or perhaps nearly contemporaneous with, the deposition of till of glaciation 3. Glacial ice moved along the strike valley parallel to the hogback supported by the Dakota Sandstone. A sharp contact between till and Morrison shale above the head of the slide for a distance of about 1½ miles suggests that the Dakota hogback was still intact at the time of deposition of the till. Glacial debris is virtually absent from the Morrison surface above the head of the slide block and from the slide block itself. It is likely that increased water supply following glaciation provided the hydrologic conditions that contributed to sliding. The Lake Agnes slide and others to the south are not clearly related to glaciation. The slide deposits are probably older than Recent, as disrupted drainages have been reestablished to a degree comparable with that on the moraines of glaciation 3.

PLEISTOCENE AND RECENT SERIES, UNDIFFERENTIATED

LANDSLIDES AND COLLUVIUM

Surficial material mapped as landslide deposits includes more or less coherent masses of material that slid downhill by force of gravity. In general, landslide deposits include material displaying typical landslide topography, or material bordered by obvious landslide scarps, whereas colluvium includes loose or incoherent material lacking typical landslide topography. Areas mapped as landslide deposits probably include colluvial material, and, conversely, areas mapped as colluvium probably include landslide material. Landslide deposits and colluvium were mapped only where thick, conspicuous, or widespread.

The most conspicuous masses of landslide and colluvium surround the high ground of the Rabbit Ears Range. Enormous masses of volcanic rock rubble derived from the Rabbit Ears Volcanics cover many square miles in the southeast corner of the Spicer Peak quadrangle and the northeast corner of the Whiteley Peak quadrangle. This rubble lies on relatively nonresistant rocks of the Coalmont and Pierre Formations. The large landslide mass just south of Chimney Rock is composed mostly of Pierre Shale. The landslide mass in the Ryder Lakes area is composed of material from the Coalmont Formation. Elsewhere, east of Muddy Creek in the Whiteley Peak quadrangle, the landslides and colluvium are composed mostly of volcanic rubble. Much of the outcrop of the sandy member of the Pierre Shale in the Whiteley Peak quadrangle is obscured by surficial rubble but not in quantities sufficient to map as a surficial unit.

Two large landslides and several small masses of colluvium lie just southeast of Muddy Creek between the DeBerard Peak Ranch and the Haworth Ranch. These are large bodies of volcanic breccia which are anomalously remote from known breccia sources. Landslide material just north of Baker Mountain, and in the area north of the high ground a mile or two east of Muddy Pass, is composed of volcanic rock debris. Elsewhere in the area, most of the landslides and colluvium are composed of locally derived sedimentary material.

RECENT SERIES

ALLUVIUM

The major stream valleys have flat alluvium-covered floors. The maximum valley-flat width is about a mile and occurs along the lower reaches of Grizzly Creek in the northeast part of the Coalmont quadrangle. There are few exposures of the alluvium, and little is known of its thickness or lithology. In many places the upper few feet is dark nongravelly loam, underlain by lighter beds containing much coarse sand and gravel.

STRUCTURE

The mapped area lies on the west flank of the North Park-Middle Park structural basin. This basin is bounded on the east by the Front Range and on the west by the Park Range. North and Middle Parks are divided topographically by the west-trending Rabbit Ears Range, a highland composed of upper Tertiary volcanic and intrusive rocks and Tertiary sedimentary rocks. In general, Eocene and older sedimentary rocks dip eastward to northeastward toward the basin axis. The gross trend of the outcropping beds is somewhat west of north, so that the structurally deepest part of the area lies in the northeast. The bordering Park Range is an anticlinal uplift and, except in the extreme northwest corner of the area, lacks the marginal faulting that marks part of the Precambrian sedimentary rock contact farther north. The general basin-flank structural setting is considerably modified locally by faulting and folding. Figure 7 is an index map showing faults and folds in the mapped area.

FOLDS AND FAULTS

NORTHEASTERN PART OF THE AREA

Several folds, numerous normal faults, and a few cross faults are present in the north-central and northeastern part of the area. Most of these involve the Coalmont Formation. Most conspicuous of the faults are the northwest-striking normal faults in the Coalmont-Pole Mountain area. None of these faults have stratigraphic displacements exceeding 500 feet and most have much less. They cut a poorly defined syncline formed in sub-Coalmont rocks which, because of the faulting, appears to be formed as a graben (pl. 1, cross section *A–A′*). Southwest of Pole Mountain, the faults are upthrown on their southwest sides. Northeast of Pole Mountain, the faults are upthrown on their northeast sides. In the Coalmont coal district these faults have repeated the outcrop of the Riach and other coal beds (Erdmann, 1941, p. 47) two to three times. The faults in the Coalmont area are as much as 6

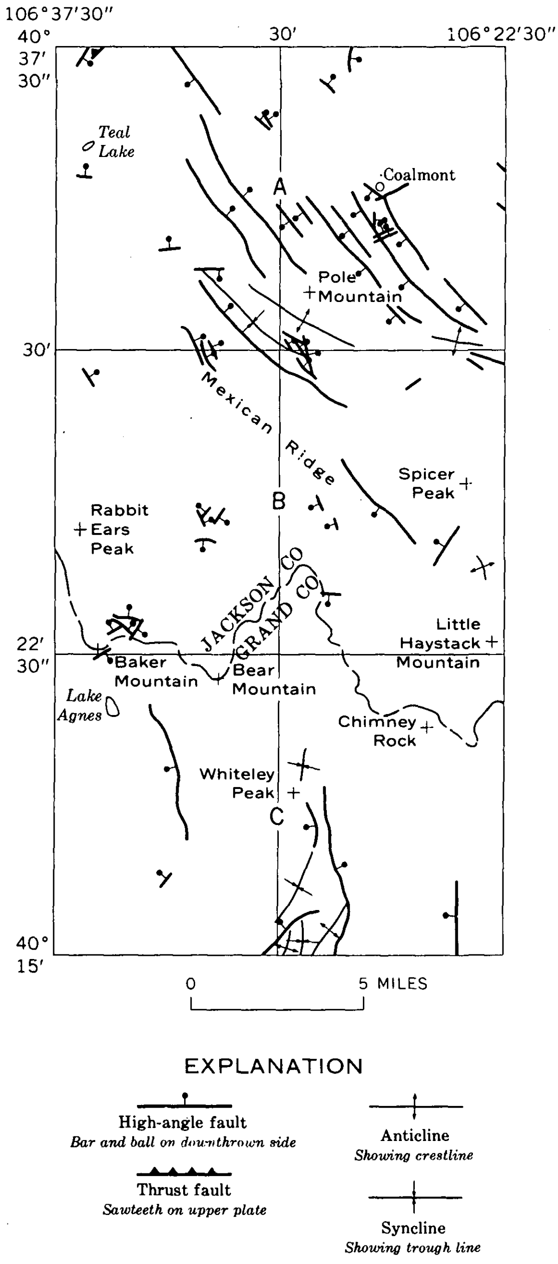

FIGURE 7.—Index map showing faults and folds. Area A refers to plate 1; B, plate 2; and C, plate 3.

miles long, and the two easternmost faults extend almost to the east boundary of the area. A small anticline about 1½ miles long in the vicinity of the Victor-Buffalo Creek test hole parallels these faults and may be genetically related to them. South of this anticline for about 3 miles, the rocks dip southwestward, and this area is structurally analogous to the area of southwest-dipping beds between an anticline and syncline southwest of Pole Mountain. The seemingly anomalous opposed dips of beds near State Highway 14 in sec. 7, T. 6 N., R. 80 W. and sec. 12, T. 6 N., R. 81 W., suggest a possible northeast-striking fault in this vicinity, but no other evidence for such a fault was seen in the field.

The subsurface structure just east of the syncline-graben may form, locally at least, as an anticlinal structure, but subsurface drill-hole information is lacking in the area east of the Hiawatha test hole, and the structure is conjectural. Surface rocks of the Coalmont Formation maintain an eastward dip.

West and southwest of Pole Mountain the structure consists of an anticline, a syncline, and a small fault. The crest line of the anticline is at least 3½ miles long in the vicinity of Mexican Creek and the North Fork of Mexican Creek. It may extend another 1½ miles to the northwest as far as the NCRA and Victor-Pony Creek test hole on Darling Creek, but surface relationships are obscure. A patch of the middle member of the Coalmont is exposed at the center of the anticline. A bordering syncline lies about three-quarters of a mile to the southwest. This syncline is about 4 miles long and is terminated by a fault at Darling Creek to the northwest and cannot be traced southeast of the faults at Mexican Creek. These faults at Mexican Creek are of small displacement, but have broken the major coal bed in the vicinity of the old mines. About a quarter to half a mile southwest of the syncline a normal fault, upthrown on the southwest, places the middle member of the Coalmont against the upper member for a distance of 3 miles. The fault itself is almost 6 miles long and extends from Darling Creek in the northwest to Grizzly Creek in the southeast. A reversal of dip must occur along a line extending roughly from the end of this fault at Grizzly Creek southwest to Spicer Peak and beyond. This line could represent in part a possible extension of the fault or an extension of the axis of the bordering syncline. The area lacks exposures adequate to determine the presence of either a fault or a syncline.

A nearly vertical fault with as much as 1,000 feet of stratigraphic displacement crosses the large bend in Grizzly Creek in the west-central part of the Spicer Peak quadrangle, and may be genetically related to the geomorphic factors producing the bend. The fault is about 3 miles long and is upthrown on the east side—opposite in throw to the fault 1½ miles north. The fault places the middle member of the Coalmont against the upper member throughout most of its length (pl. 2, cross section *B–B′*).

A northeast-striking fault extends southwestward for about 1½ miles from a point near the junction of Ninegar and Arapaho Creeks in the southeastern part of the Spicer Peak quadrangle. It is upthrown on its southeast side, and places the middle member of the Coalmont against the upper member. The fault could not be traced northeast of Arapaho Creek.

A major pre-Coalmont structural feature is indicated near the junction of the South and Middle Forks of Arapaho Creek about 2 miles north of Little Haystack Mountain. Outcrops of Dakota Sandstone and the Mowry Shale Member of the Benton Shale crop out here and are apparently unconformably overlain by the middle member of the Coalmont. The presence of Dakota and Benton indicate an uplift of about 5,000–7,000 feet relative to expected depth of burial 11 miles east of the basin margin outcrops. This structurally high area is 6–7 miles southwest of a structurally high area at Buffalo Ridge, east of the mapped area. The outcrops at Arapaho Creek are too small and scattered for determination of the nature of the uplift, but the uplift may be the result of pre-Coalmont faulting. No faults were seen in the Coalmont Formation in this vicinity, although much of the area is obscured by surficial deposits. The generally north-trending Williams Range thrust fault is not exposed farther north than the center of T. 3 N., R. 80 W., about 3 miles south of the southeast corner of the Whiteley Peak quadrangle and about 13½ miles south of the Arapaho Creek outcrops. If the Williams Range thrust trend continues northward for this distance, it might account for the structural high of this area. The Williams Range thrust, however, is dated as late or post-Middle Park by Tweto (1957, p. 29), and therefore is seemingly too young to account for the structure of this area. Pre-Coalmont folds and faults are not uncommon elsewhere in North Park.

BEAVER CREEK AREA

Near Beaver Creek in the extreme northwest corner of the area, a high-angle reverse fault of large stratigraphic displacement marks the basin margin. This fault is exposed for only half a mile in the Teal Lake quadrangle, but it continues for at least 2 miles northeastward outside the area, and very likely continues for at least 2 miles to the southwest, mostly under surficial cover. Precambrian rocks or red beds of the Chugwater are faulted upward against rocks of the Morrison Formation, Dakota Sandstone, or Benton Shale. The maximum stratigraphic displacement along the fault is at least 1,200 feet. This is the only basin-margin fault in the area. South of this fault, simple anticlinal uplift has apparently produced no faulting. A short distance to the east of the high-angle fault is an accompanying thrust fault. This fault has a maximum stratigraphic displacement of 300–400 feet. Beds of the Morrison Formation and Dakota Sandstone are thrust onto beds of the Benton Shale.

MUDDY PASS AREA

Considerable faulting is present in the area just northwest of Muddy Pass, but relationships are obscure owing to the abundant surficial cover. Two northwest-striking faults and a southwest-striking branch fault, approximately coinciding with the courses of Grizzly Creek and an unnamed creek just north of U.S. Highway 40, are upthrown on their southwest sides, placing beds of the Benton Shale against the overlying Niobrara Formation or higher beds of the Benton. These faults are terminated by a northeast-striking fault, upthrown to the northwest, which also places Benton against Niobrara or higher beds of the Benton. This fault may connect with the fault on the upper southeast slope of Baker Mountain, but it could not be traced on the ground in the intervening area. The stratigraphic displacements on the faults in this area probably do not exceed 300 feet. It is possible, though unlikely, that some of the apparently faulted units were involved in block sliding.

SOUTHWESTERN PART OF THE AREA

Most of the structure in the Lake Agnes quadrangle is characterized by simple monoclinal east- to northeast-dipping beds. A north- to northwest-striking fault, about 4 miles long, cuts the Niobrara Formation in the north-central part of the Lake Agnes quadrangle. This fault is upthrown to the east and has repeated the Niobrara and nearly doubled the usual outcrop width of the formation. The trace of this fault is obscure, but it is locally marked by seeps, and near its north end by travertine deposits. At depth the fault probably was a conduit for the intrusive trachybasalt cropping out to the west. The trachybasalt is intruded more or less concordantly into the east-dipping Niobrara and has baked and hardened the shale in the area between the outcrop and the fault, where the baked shale stops abruptly. A narrow outcrop of trachybasalt actually extends eastward to the fault. The maximum stratigraphic displacement of the fault may be as much as 600 feet.

SOUTH-CENTRAL PART OF THE AREA

Much faulting and folding characterizes the structure in the south-central part of the area. The dominant feature is a north-trending faulted anticline (pl. 3, section *C–C′*) that extends 5 miles from the hill northeast of Whiteley Peak to the south boundary of the area and beyond. The fault locally places the Niobrara Formation against the Pierre Shale, and its maximum stratigraphic displacement probably does not exceed 500 feet. The fault is intruded along part of its length by trachyandesite, and is shown on the map as coinciding with the outcropping intrusive, although it is likely that the fault may represent a zone of faulting whose main trace may not everywhere coincide with the outcrop of the intrusive. The dip of the fault plane is not well known, but dips of the intruded trachyandesite range from about 40° to nearly vertical eastward. North of Lindsay Creek, intrusive rock along the fault is lacking, as are good exposures of the Pierre Shale, and the fault is inferred.

Where the fault crosses Muddy Creek, it crosscuts the axis of a northeast-striking, rather poorly defined, anticline. Less than half a mile west of this anticline is a narrow shallow syncline whose flanks are intruded by a sill of trachybasalt and which forms the crest of a hill. Flanking this syncline about half a mile to the west is a narrow anticline, also formed in the Niobrara. Both the syncline and the anticline die out within a mile of the south boundary of the quadrangle. Southward beyond the mapped area, the two anticlines and the syncline, which together are predominantly anticlinal, become much better formed and extend southwestward several miles.

A poorly defined syncline is present in the southwest corner of the Whiteley Peak quadrangle. This syncline is separated from the anticline at the south margin of the area by a northeast-striking fault which marks the Pierre-Niobrara contact for about a mile. The synclinal axis trends northeast and is alined with a fault which begins about a quarter of a mile north of the Haworth Ranch. This fault extends northward to Whiteley Peak. It is upthrown on the east side and places the shaly member of the Pierre against the overlying sandy member. It is a high-angle, probably reverse, fault. Dips of shale beds in the Pierre are toward the fault on both sides. Near its north end, beds are vertical or steeply overturned. The fault disappears in the intrusive rock mass of Whiteley Peak, and may have provided the conduit for the intruding magma. A syncline is postulated to extend northward a mile from Whiteley Peak to the Coalmont outcrop to account for the presence of the sandy member of the Pierre, but outcrops are lacking in this area and the structure is obscure.

SOUTHEASTERN PART OF THE AREA

Much of the eastern part of the Whiteley Peak quadrangle is covered by surficial deposits and the structure underlying the area is unknown. Outcrops are very poor in the remainder of the area that is underlain by the sandy member of the Pierre Shale. Sparse dip and strike readings, however, suggest that the Pierre in this area may flatten or reverse from its generally eastward dip. A broad structural flat or syncline is shown on the cross section *C–C′*, plate 3. It is possible that pronounced local structural features are present in this area. A change in strike from the usual northwestward to northeastward takes place at the southeast corner of the area. The Pierre is covered by Tertiary rocks within a mile or so east of the Whiteley Peak quadrangle.

AGE OF DEFORMATION

Paleozoic rocks older than Permian are absent from the area and and a record of Paleozoic tectonic activity is not present. The so-called Ancestral Rockies were formed in Pennsylvanian time when part of the present mountain area of central Colorado, including the mapped area, was elevated and eroded to a nearly flat surface cut on Precambrian rocks. If rocks older than Permian were ever present in this area, they were removed by Pennsylvanian and Early Permian erosion. The Precambrian erosion surface on which the oldest sedimentary rocks of this area were deposited was a surface of little relief rising very gradually to the south or southeast. In surface exposure the basal sedimentary rock is the Chugwater Formation of Permian and Triassic age. Farther east in the subsurface the basal unit is the Sundance Formation of Late Jurassic age.

Pre-Laramide Mesozoic tectonic activity in the area was not great as indicated by the absence of angular unconformities in the Mesozoic rocks. Occasional moderate uplift and erosion, however, are indicated by unconformities: (1) between the Chugwater and the Sundance Formations, (2) possibly between the lower and upper members of the Sundance, (3) locally between the Morrison Formation and Dakota Sandstone, (4) within the Dakota Sandstone and, (5) possibly between the middle shaly member and the Codell Sandstone Member of the Benton Shale. Probably the largest of these unconformities is the one separating the Chugwater from the Sundance. Near the south end of Tyler Mountain, 6 miles south of the mapped area, about 80 feet of beds, probably equivalent to the Chinle Formation of Triassic age, overlies beds equivalent to the Chugwater of this area. These beds are absent in Barber Basin and probably elsewhere in the mapped area. In addition, an unknown but probably considerable thickness of

Chugwater was removed by erosion prior to deposition of the Sundance.

The earliest events of Laramide tectonism are not known because of the absence of the upper part of the Pierre Shale and younger Cretaceous rocks. Presumably these Cretaceous rocks were removed by erosion following earliest Laramide uplift probably in latest Cretaceous time. This early uplift resulted in the rise of the Park Range and Medicine Bow-Front Range to outline the west and east margins of the North Park-Middle Park basin. Marginal uplift accompanied central basin downwarp probably in latest Cretaceous and earliest Tertiary time, and was followed by folding, faulting, and erosion of pre-Tertiary rocks to form a major unconformity between Tertiary and older rocks. This period of erosion laid bare the Precambrian core of the Park Range prior to the beginning of earliest Tertiary deposition which began in Paleocene time.

Evidence of the pre-Coalmont uplift occurs near Rabbit Ears Peak, where the Coalmont overlaps the entire pre-Tertiary sedimentary sequence; near Rabbit Ears Pass where the Coalmont lies on rocks of the Morrison and Sundance Formations; and near Arapaho Creek where the Coalmont lies on rocks of the Dakota Sandstone and Benton Shale. Elsewhere east of the basin flank, the Coalmont mostly lies, with moderate angular unconformity, on rocks of the Pierre Shale. The anticline southeast of Whiteley Peak and the bordering syncline northwest of Whiteley Peak apparently are not reflected in the Coalmont Formation to the north. This fact indicates that the folds in this area are pre-Paleocene in age. Faults cutting these folds, however, are probably post-Eocene in age.

Deposition of the Coalmont Formation started during Paleocene and continued into early Eocene time and was accompanied by continued rise of bordering ranges and downwarp of the basin. Parts of the Coalmont itself were raised and eroded in this process, and at least one, and possibly several, intraformational unconformities were produced.

The absence of Tertiary rocks younger than Coalmont in much of the area makes uncertain the dating of Eocene and younger structural events. Elsewhere in North Park an unconformity between the Coalmont Formation and the White River Formation of Oligocene age indicates post-early Eocene uplift and erosion, and an unconformity between the White River and the North Park Formation of late Miocene age indicates post-Oligocene uplift and erosion.

The numerous northwest-striking faults and associated folds in the Coalmont Formation in the northeastern part of the area are Eocene or younger. The northwestward trend of these faults and folds is roughly parallel to the trend of the North Park syncline a few miles north of the area. This trend suggests a possible genetic and time relationship. The North Park syncline is dated as latest Miocene or Pliocene.

Volcanic activity began in the area probably in late Oligocene time with the initial deposition of the breccias and flows of the Rabbit Ears Volcanics, and continued probably at least to late Miocene, and possibly into the Pliocene. Although the dating of many of the isolated intrusives in the western and southern parts of the area is uncertain, it is assumed that these intrusives were contemporaneous with the Oligocene and Miocene volcanism. Many of these intrusives are associated with faults and folds, and although most of the folding in this area is probably pre-Paleocene, some of the faulting and late Tertiary volcanism were contemporaneous.

Outcrops of the late Tertiary rocks are too sparse to afford evidence of post-Miocene deformation. Continued marginal uplift and basin deepening is suggested by the eastward migration of north-trending stream valleys, as recorded by successively lower terrace levels in an eastward or southeastward direction. The valley of north-flowing Grizzly Creek, for example, has migrated more than 4 miles to the east in the northern part of the Coalmont quadrangle since early Pleistocene time.

ECONOMIC GEOLOGY

No minerals are produced in the area at the present time (1965), although coal production from the Coalmont district has been large in the past. A small amount of manganese has been produced near Rabbit Ears Pass, and large amounts of gravel are used locally for road surfacing. There has been much prospecting, however, for oil and gas and for uranium and other minerals.

COAL

In past years the Coalmont district was a large producer of coal. Erdmann (1941) made a detailed study of the geology and coal resources of the Coalmont district in 1934 and 1940 when mining and exploration were still being carried on. Erdmann's report is not published but is available in the open files of the U.S. Geological Survey. Erdmann's area of investigation included approximately the following: secs. 23, 24, 25, 26, 36, and the NE¼ sec. 35, T. 7 N., R. 81 W., and parts of secs. 30 and 31, T. 7 N., R. 80 W. Beekly (1915, p. 102–107 and plate X) examined coal beds in the Coalmont-Pole Mountain-Mexican Creek area in 1912, and measured several coal sections.

Coal was first mined commercially about 1909 in the Coalmont district and continued to be mined until about the close of World War II. The district lay idle until about 1959 when a new strip pit was opened in the NE¼ sec. 23, T. 7 N., R. 81 W. Some coal was hauled out and sold in the Denver area, but operations ceased a year or two later and there has been no production since that time, although recently (1964–65) there has been some prospecting work.

Erdmann (1941, p. 2–3) estimated total production to 1941 at 1,438,355 tons, and the original reserves at 177,450,000 tons. The coal is subbituminous B rank, according to analyses presented by Erdmann (1941, p. 65).

The thickest coal bed in the Coalmont district is the Riach coal bed (fig. 8), which ranges from 25 to 80 feet in thickness (Erdmann, 1941, p. 1). The coal occurs in the lower part of the upper member of the Coalmont Formation. The Riach and other coal beds are lenticular and grade laterally into carbonaceous shale within a few thousand feet.

Coal is present in the Pole Mountain-Mexican Creek area, southwest of Coalmont; it occurs also in the lower part of the upper member of the Coalmont. Coal was mined there for local ranch use, but the mines were apparently abandoned long before Beekly visited

FIGURE 8.—Riach coal bed in upper member of Coalmont Formation in old strip pit near Coalmont. Coal bed forms the dark cliff. Ladder at lower right is about 16 feet long. NW¼ sec. 26, T. 7 N., R. 81 W.

the area in 1911 (Beekly, 1915, p. 105–106). At least two beds are present on the west side of Pole Mountain, about 90–120 feet apart stratigraphically. These and other outcropping beds are shown on the geologic map. The beds are lenticular, discontinuous, grade laterally to carbonaceous shale, and in much of the area are very poorly exposed or are covered. Structural complexities, mostly faulting, make stratigraphic relations obscure, and no attempt was made to correlate the various coal beds or to calculate reserves.

Detailed coal sections were measured, or outcrops examined at 15 localities in the Pole Mountain-Mexican Creek area:

Locality 1, NW¼ sec. 3, T. 6 N., R. 81 W.

	Feet
Carbonaceous shale	3+
Clinker	1–3
Interbedded shaly coal and coaly shale	11
Carbonaceous shale becoming coaly near top	5
Shale, coaly	1
Carbonaceous shale	3
Coal, shaly	1
Shale, coaly	1
Coal, shaly; carbonaceous shale on bedding surfaces	8
Carbonaceous shale	5
Base of zone covered.	

Locality 2, NE¼ sec. 4, T. 6 N., R. 81 W.

Sandstone, light-brownish-gray, micaceous, coarse-grained massive, nonresistant; calcareous resistant ledge in lower part	45
Shale, clayey, fissile, brown to gray, slightly carbonaceous	1
Carbonaceous shale	7
Coal, slightly clayey, shaly structure	3
Carbonaceous shale, slightly coaly	9
Carbonaceous shale	22
Coal, shaly	9
Carbonaceous shale, coaly	13
Clinker	1–2
Carbonaceous shale	10
Lower beds covered.	

Locality 3, SW¼ sec. 33, T. 7 N., R. 81 W.

Interbedded carbonaceous and clay shale, fissile, noncoaly; contains a few siltstone concretions; unit extends to top of hill	25
Interbedded clay shale and siltstone	7
Siltstone, concretionary; weathers rusty brown	1
Carbonaceous shale, interbedded coaly and noncoaly; contains a few thin siltstone and sandstone beds	10
Sandstone, light-brown, coarse-grained, micaceous, lenticular, crossbedded, calcareous; forms ledge	2
Carbonaceous shale containing a few coaly streaks along bedding planes	8
Sandstone, light-yellowish-gray to white, coarse-grained, micaceous, massive, nonresistant	10+

The coal at locality 3 has evidently burned to form the clinker-capped hill about 500 feet to the southwest.

Locality 4, NE¼ sec. 4, T. 6 N., R. 81 W.

	Feet
Covered interval, apparently carbonaceous shale and a few sandstone beds	66
Clinker; evidently at least two coal beds have burned to form the clinker, inasmuch as there is a thin bed of coal ash present in the upper part of the unit	21
Carbonaceous shale	50

Locality 5, NW¼ sec. 4, T. 6 N., R. 81 W.

Poorly exposed interval, apparently mostly nonresistant micaceous sandstone	30+
Carbonaceous shale and brown clay shale	5
Shale, gray, clayey, fissile	1
Coal, shaly	2½
Coal, contains a few shaly partings	5½
Carbonaceous shale	14
Shale, clayey, gray to brown, fissile to platy	100+

Locality 6, SW¼ sec. 33, T. 7 N., R. 81 W.

Thin clinker here, indicating that part of the coal in the zone has burned, but material from animal burrows just below clinker indicates that some unburned coal is present.

Locality 7, NW¼ sec. 28, T. 7 N., R. 81 W.

Poor exposure of coal in gully; top and bottom covered, but coal is at least 6 feet thick, fairly pure, but with shaly structure.

Locality 8, SW¼ sec. 21, T. 7 N., R. 81 W.

	Feet
Carbonaceous shale, to top of hill	10+
Coal, containing a few shaly coal interbeds	2
Carbonaceous shale, coaly	2½
Coal, shaly	1
Carbonaceous shale	6
Coal	3
Coal, somewhat shaly; makes obscure ledge	2
Coal, interbedded with shaly coal	6
Coal, shaly	2
Carbonaceous shale, coaly	1½
Coal, shaly	2½
Siltstone, shaly, light-brown	1
Coal, shaly	½
Shale, coaly, silty	½
Carbonaceous shale, coaly	3
Covered interval, apparently coaly carbonaceous shale as above	10+

This section (locality 8) was measured near an old abandoned coal mine. The entry is completely caved and inaccessible. This is apparently the mine Beekly (1915, p. 105) referred to as the old Taylor mine, where he measured a coal section consisting of two benches of coal separated by a 14-inch shale parting; the lower bench was reported to be more than 4 feet thick, the upper bench to be 4½ feet thick.

Locality 9, SE¼ sec. 21, T. 7 N., R. 81 W.

	Feet
Carbonaceous shale; higher beds covered	4+
Poorly exposed interval, appears to be coaly carbonaceous shale with interbeds of shaly coal	6
Carbonaceous shale, coaly; makes obscure ledge	1
Coal, shaly, badly weathered	2
Carbonaceous shale, coaly, silty; makes obscure ledge	½
Coal, shaly; shale parting near middle	3½
Interbedded coaly shale and carbonaceous shale	2+
Lower beds covered.	

The coal at localities 10 and 11 is exposed in a landslide mass. The coal bed is not shown on the geologic map. The landslide probably has not moved far, and the sections are included to indicate the nature of the coal beds that may underlie this part of the east slope of Pole Mountain.

Locality 10, SW¼ sec. 27, T. 7 N., R. 81 W.

	Feet
Shale, light-brown	10+
Shale, coaly	2
Coal	2½
Carbonaceous shale	5

Locality 11, SE¼ sec. 28, T. 7 N., R. 81 W.

	Feet
Covered interval, probably coaly shale and carbonaceous shale	12
Coal, shaly	6
Mostly covered, apparently all carbonaceous shale	16
Shale, coaly	3
Coal, shaly; contains some shale interbeds and a few siltstone stringers	14
Carbonaceous shale, coaly	4
Siltstone, weathers rusty brown	½
Carbonaceous shale, somewhat coaly	5
Carbonaceous shale; somewhat coaly; contains a zone of ironstone concretions	4
Shale, coaly	8
Carbonaceous shale, fissile; contains a few coaly streaks	7
Covered interval; apparently brown clay shale	30+

Coal sections 12 and 13 are in the same bed. Between these two localities, at the abandoned mine shown on the map, no section was measured, but at least 22 feet of coal is exposed.

Locality 12, NE¼ sec. 8, T. 6 N., R. 81 W.

	Feet
Interbedded siltstone and silty brown shale	5+
Interbedded coaly shale and lesser shaly coal	9½
Coal, shaly structure	3
Interbedded coal, shaly coal, and coaly shale	7½
Coal, shaly structure; 2-in.-thick shale bed 8 ft. above base	9½
Coal, shaly; forms obscure ledge	½
Coal, shaly structure	5
Shale, brown, carbonaceous, silty; contains a few siltstone and ironstone concretions	30+

Locality 12 is evidently the site of a long-abandoned mining operation.

Locality 13, SW¼ sec. 5, T. 6 N., R. 81 W.

	Feet
Clinker; indicating presence of burned coal bed below	2
Mostly covered interval; probably carbonaceous shale	27
Carbonaceous shale, silty	½
Coal	1½
Carbonaceous shale, coaly	½
Coal	1½
Carbonaceous shale, coaly	½
Interbedded coal and shaly coal	2½
Carbonaceous shale, coaly	½
Coal, shaly, interbedded with lesser coaly shale	3½
Carbonaceous shale, coaly	4
Carbonaceous shale	15+

Sections at localities 14 and 15 are in the same bed; this bed crops out near Mexican Creek where some coal has been mined in the past.

Locality 14, SW¼ sec. 9, T. 6 N., R. 81 W.

	Feet
Carbonaceous shale; contains a few coaly streaks	10+
Carbonaceous shale, coaly	4
Shale, slightly carbonaceous	1
Coal, shaly	1½
Coal	½
Carbonaceous shale, coaly	2
Coal	2
Carbonaceous shale	½
Coal	1½
Carbonaceous shale	2
Coal	4
Carbonaceous shale	1

Lowerd beds covered.

Locality 15, SW¼ sec. 9, T. 6 N., R. 81 W.

	Feet
Siltstone, rusty, concretionary	1½
Carbonaceous shale	½
Coal, shaly	1
Shale, coaly	2
Coal, shaly	2½
Interbedded carbonaceous shale and shaly coal	2½
Coal, slightly shaly	4½
Shale, coaly	2+
Lower beds covered.	

Thin lenticular coal beds crop out elsewhere in the area but most have little or no commercial potential. A coal bed was mapped half a mile north of Grannys Nightcap, in sec. 3, T. 4 N., R. 81 W. The bed is at least 3 feet thick in places, and occurs in a carbonaceous shale zone in the lower member of the Coalmont Formation.

MANGANESE

A small manganese deposit, now inactive, is just east of old Rabbit Ears Pass in the center of the SW¼ sec. 9, T. 5 N., R. 82 W. Manganese was produced from bouldery surficial rubble of trachybasalt. The mineral is psilomelane which occurs as botryoidal masses, or as vesicle fillings or coatings on the trachybasalt. Several prospect pits have been dug into outcrops of the trachybasalt flow just west of the mapped area, but actual mining operations have been confined to the surficial material. All shipments were made to the Federal Government stockpile.

GRAVEL

Gravel resources are abundant and have been utilized locally for road construction. The principal sources of gravel are the Quaternary terrace gravels. A gravel pit in the NW cor. sec. 8, T. 5 N., R. 81 W., lies in a patch of colluvium rubble. Two sand pits in sec. 5, T. 5 N., R. 81 W., were developed in arkosic sand of the middle member of the Coalmont Formation.

Most of the gravel pits in the area lie in the Grizzly Creek drainage basin, and consist of dark volcanic rock material. The large terrace gravel flat between Little Grizzly and Chedsey Creeks is composed entirely of granitic constituents. The large gravel pit in the SE¼ sec. 23, T. 6 N., R. 81 W., furnished material for paving much of State Highway 14 south to Muddy Pass in this area in 1961, and for paving the new section of U.S. Highway 40 over relocated Rabbit Ears Pass in 1963.

OIL AND GAS

No oil or gas has been discovered to date (1965) in the area, although several test holes have been drilled. Three small productive fields in eastern North Park suggest that large areas of North and Middle Park basin may be potentially favorable for oil and gas discovery.

The M. E. Davis State 1 test hole was drilled near Coalmont in 1952. A drill stem test in fractured beds of the Codell Sandstone Member (Frontier sand of economic usage) of the Benton Shale resulted in a flow of gas and 42.7 gravity oil at an estimated rate of 35 barrels of oil per hour. Owing to circulation problems, the well could not be completed and was shut in and abandoned. Drilling of the nearby Hiawatha, Lockhart Fuller 1 and Lockhart Government 1 test holes was unsuccessful (Severy and Thompson, 1953, p. 141, and Henkes, 1957, p. 94–96).

In the productive fields of eastern North Park, oil has been produced from the upper member of the Dakota Sandstone (Dakota sand of economic usage), the lower member of the Dakota (Lakota sand of economic usage), sandstone beds of the Morrison Formation, and the lower member of the Sundance Formation. Gas has been produced from various parts of the Dakota Sandstone.

Ten significant test holes have been drilled in the area, most of them in the Coalmont quadrangle. These are as follows:

Name	Year drilled	Location			Surface formation	Lowest formation or unit penetrated	Total depth (feet)
		Sec.	T. (N.)	R. (W.)			
Hiawatha Oil and Gas Government 1.	1953	SW¼SW¼ 25	7	81	Coalmont	Precambrian rocks.	8,244
M. E. Davis State 1	1952	NW¼NW¼ 36	7	81	do	Benton	6,920
L. M. Lockhart Fuller 1	1953	SE¼NE¼ 35	7	81	do	Morrison(?)	8,116
Producers and Refiners Hendershot 1.	1930	SE¼NE¼ 2	6	81	do	Pierre	4,258
L. M. Lockhart Government 1.	1954	NE¼NW¼ 11	6	81	do	Morrison	7,841
NCRA and Victor Pony Creek 1.	1956	NE¼NE¼ 36	7	82	do	do	4,480
Midwest Refining Rich 21X.[1]	1928–30	SW¼NW¼ 9	6	81	do	Pierre	4,500
Victor Buffalo Creek 1	1956	NW¼SE¼ 8	6	80	do	Morrison	8,486
Walters State 1-B	1960	SE¼SE¼ 21	4	81	Pierre	do	3,360
DeBerard State 1	1952	NW¼SW¼ 27	4	81	do	Precambrian rocks.	4,705

[1] Not shown on geologic map—exact location unknown.

Oil and gas in eastern North Park is produced from anticlinal structures. Although several anticlines are present in southwestern North Park it is doubtful that they have been adequately tested for oil and gas. The Victor-Buffalo Creek test hole was drilled on an anticline in the southeast corner of the Coalmont quadrangle. The NCRA and Victor-Pony Creek test hole was drilled on the north extension of a northwest-trending anticline, about 4 miles long, in the area of Mexican Creek and the North Fork of Mexican Creek. The DeBerard and Walters test holes, in the southern part of the area, were drilled half a mile or so east of the surface crest line of the north-trending fault-anticline structure in the western part of the Whiteley Peak quadrangle. The amount of structural closure, if any, on the three anticlines is not known. Two rather poorly defined anticlines enter the area, in the extreme southwest corner of the Whiteley Peak quadrangle.

Possible geophysical prospecting for favorable anticlinal structures should be directed to areas covered by surficial deposits and areas overlain by the Coalmont Formation. Pre-Coalmont structural features are present elsewhere in North Park, and are likely to be present in this area. Most of the Coalmont and Spicer Peak quadrangles and much of the Teal Lake and Rabbit Ears Peak quadrangles are covered by the Coalmont. A large area of the Whiteley Peak quadrangle is covered by surficial deposits, both mapped and unmapped.

Fault structural features have not been adequately tested in North Park, but the finding of oil in the M. E. Davis test hole in fractured rock of the Codell Sandstone Member of the Benton Shale strongly suggests the likelihood of fault-related oil entrapment.

Potentially productive sandstone beds, such as the lower member of the Sundance Formation and the lower member of the Dakota Sandstone, have considerable variations in thickness. This variation suggests the possibility of stratigraphic entrapment, but no consistent trend of thinning is apparent, and evaluation of such possibilities would be difficult. In the south part of the area the Chugwater Formation pinches out completely eastward between the outcrop at Barber Basin and the DeBerard test hole, within a distance of 5 miles, by nondeposition of lower beds against a rising Precambrian surface. Should this rise continue farther east, the lower member of the Sundance might also pinch out and with a reversal in the generally eastward regional dip, might provide a potential stratigraphic trap.

URANIUM

Considerable prospecting for uranium was carried on in the early and middle 1950's with mostly negligible results. The most promising uranium mineralization was found in the Dakota Sandstone in the area between Rabbit Ears Pass and the gap cut by Muddy Creek through the Dakota hogback at Barber Basin. Considerable drilling and pit prospecting was carried on in this area intermittently until about 1959. This mineralized area, known as the Humes claims, was examined by R. C. Malan of the U.S. Atomic Energy Commission

(Malan, 1957, p. 135–136). According to Malan, mineralization conforms to the attitude of the bedding and is confined to three zones in the upper 25 feet of the Dakota. Carnotite and lesser amounts of autunite are concentrated by carbonaceous material in this interval, and in a silicified sandstone on the dip slope just below the Benton contact. Malan postulated that mineralizing meteoric waters precipitated the uranium. He mentioned the proximity of igneous flows and intrusives, but pointed out that no genetic relationship between uranium and volcanic activity was known.

No commercially important amounts of uranium were taken from the Humes claims, and the area is now (1965) inactive. Considerable prospecting was done along the entire length of the Dakota hogback in the area, but with little or no success.

OTHER MINERALS

Numerous prospect pits and claim stakes, mostly in areas of Precambrian rock, indicate prospecting in the past for various minerals, reportedly fluorspar, gold, and rare earths; but to date (1965) no commercially important mineral deposits have been found.

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INDEX

[Italic numbers indicate major references]

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