Geology of Northwestern North Park, Colorado

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A study of the stratigraphy and areal geology of part of the North Park basin Jackson County, Colorado

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CONTENTS

ILLUSTRATIONS

[Plates are in plate volume]

TABLE

GEOLOGY OF NORTHWESTERN NORTH PARK, COLORADO

By William J. Hail, Jr.

ABSTRACT

Northwestern North Park is an area of about 340 square miles, occupying the northwestern part of the North Park basin, Jackson County, Colo. North Park is a large intermontane topographic basin, almost surrounded by mountain ranges, that constitutes the northern half of the North Park–Middle Park structural basin. The east flank of the Park Range forms the western border of the area. Independence Mountain is a prominent highland which crosses the northern part of the area. A narrow north-trending highland area, including Delaney Butte and Sheep Mountain, extends through the north-central part of the area. Maximum elevations of the various highland areas range from about 9,300 to 11,600 feet. The remainder of the area is lowlands, generally of little relief, ranging in elevation from about 7,900 to 8,600 feet. The entire area is drained by the north-flowing North Platte River. The climate is characterized by long cold winters and short cool summers. Rainfall is variable: the bordering mountainous areas are moist, and the basin lowlands are arid. Stock raising is the principal occupation; timber resources are abundant.

Precambrian crystalline rocks in the area are divided into two mapped units: a metamorphic complex consisting chiefly of gneiss, and a younger igneous intrusive body consisting chiefly of quartz monzonite. Precambrian rocks form most of the highlands which, in the northern part of the area, consist mainly of metamorphic rocks, and in the southern part, of quartz monzonite. The most abundant metamorphic rocks are felsic gneiss of granitic or quartz monzonitic composition and hornblende gneiss; pegmatite is locally abundant. The intrusive quartz monzonite is a pink, red, or gray medium-grained rock of granitic texture. Its average composition is 35 percent quartz, 32 percent oligoclase, 28 percent microcline, and 5 percent biotite.

The sedimentary rock sequence ranges in age from Late Permian to Quaternary. Sedimentary rocks older than Late Permian are absent owing to erosion or nondeposition in this part of the Front Range highland of the so-called Ancestral Rocky Mountains. Pre-Quaternary sedimentary rocks have a maximum thickness of about 17,000 feet.

The oldest formation is the Chugwater Formation of Permian and Triassic age; it has a maximum thickness of 860 feet. The Chugwater consists mostly of marginal-marine red beds including shale, siltstone, and sandstone. Included in the lower part of the Chugwater in the northern part of the area are possible equivalents of the Satanka Shale and the Forelle Limestone. Included in the upper part of the Chugwater is the equivalent of the Jelm Formation, which is a nonmarine conglomeratic unit unconformably overlying the marine red beds.

The Sundance Formation of Jurassic age, which has a maximum thickness of 150 feet, unconformably overlies the Chugwater Formation. It consists of two members: a lower member consisting of nonresistant fine-grained light-gray sandstone, and an upper member consisting of light-gray to green glauconitic marine shale and sandstone. Conformably overlying the Sundance is the Morrison Formation of Jurassic age. The Morrison has a maximum thickness of 430 feet; it consists of nonmarine varicolored claystone and siltstone and brown calcareous sandstone in the lower part and predominantly of greenish-gray claystone and siltstone in the upper part.

The Dakota Sandstone of Early Cretaceous age unconformably overlies the Morrison Formation and has an aggregate maximum thickness of 235 feet. It comprises the Lytle and South Platte equivalents, which are apparently separated by an unconformity. The Lytle equivalent is predominantly nonmarine conglomerate and conglomeratic sandstone which locally contains light-gray, green, or red claystone and siltstone. The South Platte equivalent is shallow-water marine sandstone and siltstone and dark marine shale. The Dakota Sandstone generally contains the most resistant rocks of the entire sedimentary sequence in this area and generally forms hogbacks. Conformably overlying the Dakota Sandstone is the marine Benton Shale of Early and Late Cretaceous age. Its maximum thickness is 650 feet, and it comprises three units. The lowest unit is the Mowry Shale Member. It consists of beds of dark platy shale that weathers to light shades and contains sparse bentonite. The top of the Mowry is the Early-Late Cretaceous boundary. Overlying the Mowry Shale Member is the middle shaly member consisting of dark noncalcareous shale which has a few bentonite beds and ironstone concretions in the lower part, a thin limestone bed near the middle, and calcareous shale in the upper part. The upper or Codell Sandstone Member consists of resistant interbedded sandy limestone, calcareous sandstone, and dark shale. It forms hogbacks in many places. Overlying the Benton Shale with probable unconformity is the Niobrara Formation of Late Cretaceous age; its maximum thickness is 720 feet. The Niobrara comprises the Fort Hays Limestone Member, consisting of interbedded limestone and dark calcareous shale, and the overlying Smoky Hill Shale Member, consisting mostly of gray, brown, and yellow calcareous platy shale. The Pierre Shale of Late Cretaceous age conformably overlies the Niobrara Formation. The Pierre consists of a shaly member in the lower part and a sandy member in the upper part. The shaly member is almost entirely dark nonresistant marine shale, virtually noncalcareous except in its lower part; its maximum thickness is about 3,000 feet. The sandy member consists of interbedded nonresistant marine calcareous sandstone and noncalcareous siltstone and shale. Thin nonmarine coaly sandstone beds are present locally. The maximum preserved thickness of the sandy member is 2,200 feet. Several thousand feet of younger Cretaceous rocks known to exist nearby have apparently been eroded from the area. These missing strata mark a major unconformity that separates Tertiary rocks from Pierre and older rocks.

The oldest Tertiary formation is the Coalmont Formation of Paleocene and Eocene age. The Coalmont has an estimated maximum thickness of about 7,000 feet. It consists of a heterogenous mixture of nonmarine feldspathic sandstone, conglomerate, conglomeratic sandstone, sandy claystone, and some carbonaceous shale. Recent discovery and identification of fossil pollen and spores has permitted the assignment of an Eocene age to beds of the upper part of the Coalmont. A thin wedge of the White River Formation of Oligocene age is present in the southeastern part of the area, where it unconformably overlies the Coalmont Formation. It consists of calcareous tuffaceous claystone, siltstone, and sandstone and has a maximum thickness of about 230 feet. The youngest Tertiary formation in the area is the North Park Formation of late Miocene age. The North Park unconformably overlies both the White River and the Coalmont Formations in the southeastern part of the area and overlies rocks as old as Precambrian in the northern part of the area. It consists of grayish-orange to light-gray calcareous ashy sandstone, volcanic pebble conglomerate and conglomeratic sandstone, and a few beds of limestone, tuff, and volcanic ash, which have a maximum remaining thickness of about 1,100 feet. A local deposit of boulder conglomerate of Pliocene(?) age caps Independence Mountain.

Pleistocene deposits include till and related outwash and terrace gravels of three glaciations, older terrace gravels, and alluvial fan and pediment gravels. The oldest till, designated drift of glaciation 1 (pre-Wisconsin age), occupies interstream divides and has no recognizable morainal form. Older terrace gravels of pre-Wisconsin age may be glacial in origin but cannot be correlated with glacial till. The older of two major valley glaciations, both of Wisconsin age, is represented by till, outwash, and glaciofluvial terrace gravels, which are designated drift of glaciation 2. Younger till, outwash, and glaciofluvial terrace gravels are designated drift of glaciation 3.

Recent deposits include fresh glacial till in or near cirques, alluvium along the larger streams, and a small local deposit of travertine.

Deposits of undifferentiated Quaternary age include scattered thin gravel deposits composing alluvial fans or capping pediment surfaces, and colluvium, hillwash, and landslides.

The mapped area occupies part of the west flank of the North Park basin. Most of the major structural features are related to Laramide or younger tectonism. Irregular high-angle faults mark the margin of the basin along the flank of the Park Range uplift. In the area between the margin and trough of the basin, a line of north- to northwest-striking east-dipping thrust faults, most of which are faulted anticlines, produce high scarps of Precambrian rocks. The anticlines are mostly post-Pierre and pre-Coalmont in age, but the major movements of the thrust faults are post-Coalmont in age. Between the thrust-fault belt and the basin margin are other folds and faults. The west-striking north-dipping Independence Mountain thrust fault crosscuts the other, predominantly north-trending, structural features.

The North Park syncline, of late Miocene or younger age, is a narrow west-striking trough that extends across much of central North Park and into the southeastern part of the area. A fault parallels the syncline on its north side. Normal faults of late Miocene or younger age separate the Precambrian rocks of Independence Mountain and the Tertiary strata in places.

No minerals are produced now in the area, although there has been considerable prospecting for copper, gold, and uranium; small amounts of coal and fluorspar have been produced in the past. Coal reserves are negligible, but sufficient gravel is produced for maintenance of local roads.

INTRODUCTION

LOCATION

Northwestern North Park is an area of about 340 square miles in the northwestern part of Jackson County, Colo. (fig. 1). North

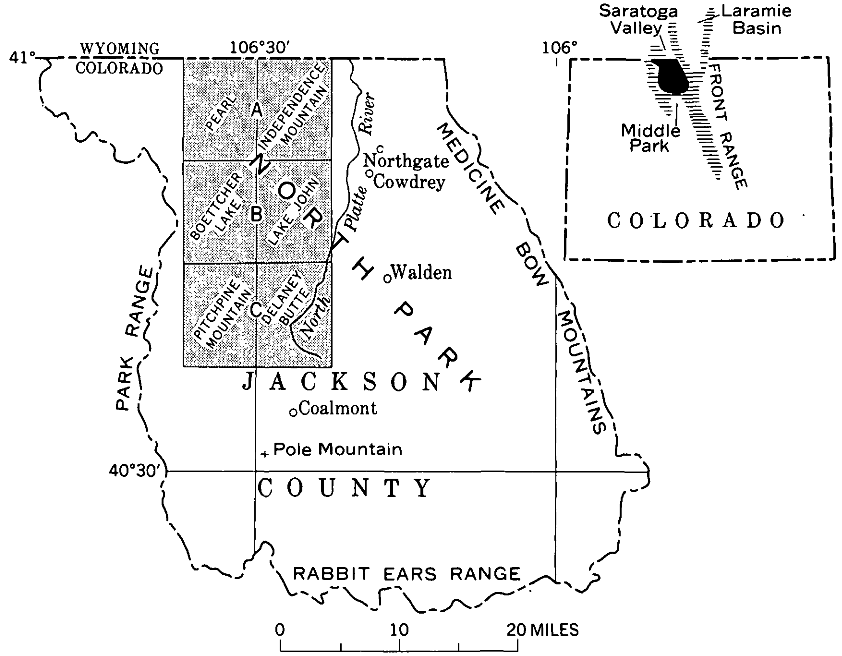

FIGURE 1.—Location of the report area (stippled). Area A refers to plate 1; B, plate 2; and C, plate 3.

Park is a broad intermontane topographic basin, which is generally considered to be coextensive with all but the northern fringe of Jackson County. The park constitutes the north half of the North Park-Middle Park structural basin. The area of this report comprises the following 7½-minute quandrangles: Pearl, Independence Mountain, Boettcher Lake, Lake John, Pitchpine Mountain, and Delaney Butte. (See index map, fig. 1.) Geologic maps of these quadrangles are shown on three sheets (pls. 1, 2, 3).

PREVIOUS WORK

The earliest geologic work in North Park was done by geologists of the U.S. Army's 40th Parallel Survey, directed by Clarence King, and of the U.S. Department of Interior's Territorial Surveys, directed by F. V. Hayden. Rapid reconnaissances were made during the late 1860's and the 1870's. References to the geology of North Park in publications of the 40th Parallel Survey appear in volume one by King (1878), in volume two by Hague and Emmons (1877), and in the Atlas by King (1876). References to the geology of North Park in publications of the Territorial Surveys appear in volume two (Hayden, 1868), and in the Colorado Atlas (Hayden, 1877). A. R.

Marvine of the Territorial Surveys studied the geology of North Park in 1874, but he died before the results of his work could be written for publication. Spencer (1903) examined copper prospects near Pearl in the northwestern part of the area. Beekly (1915) made a study of North Park and published a report including a geologic map at a scale of 1:125,000. Atwood (1937) described the main features of glaciation in the Medicine Bow and Park ranges in the North Park area. Guidebooks by the Wyoming Geological Association (1953) and the Rocky Mountain Association of Geologists (1957) contain papers on the geology of North Park.

Several unpublished university theses describe the geology in parts of northwestern North Park. These include:

Barnes, W. C., 1958, Geology of the North Park syncline area, Jackson County, Colo.: Wyoming Univ. Master's thesis.

Oppel, R. E., 1953, Geology of the Sheep Mountain area, Jackson County, Colo.: Colorado School Mines Master's thesis.

Rollins, J. F., 1952, Stratigraphy and structure of the Sheep Mountain area, North Park, Jackson County, Colo.: Nebraska Univ. Master's thesis.

Wakefield, L. W., 1952, Geology of the Boetcher Ridge-Sheep Mountain-Delanos Butte area, North Park, Colo.: Colorado Univ. Master's thesis.

Walters, R. F., 1953, Geology of the Independence Mountain area, North Park, Colo.: Wyoming Univ. Master's thesis. See also modified summary, *in* Rocky Mountain Assoc. of Geologists Guidebook to the geology of North and Middle Parks basin, Colorado, 1957: p. 85–89.

Welsh, J. E., 1951, Geology of the Sheep Mountain-Delaney Butte area, North Park, Jackson County, Colo.: Wyoming Univ. Master's thesis. See also summary, *in* Wyoming Geol. Assoc. Guidebook, 8th Ann. Field Conf., Laramie Basin, Wyoming, and North Park, Colorado, 1953: p. 99–100.

FIELDWORK

The field investigations were made during the summers of 1956, 1957, and 1958. Geologic mapping was done chiefly on aerial photographs at a scale of 1:28,000 and compiled on the topographic base maps by multiplex projection. Lawrence D. Taylor assisted in the geologic mapping during the field season of 1958.

GEOGRAPHY

TOPOGRAPHY

North Park is a large intermontane basin almost entirely surrounded by mountains. The area of this report covers most of northwestern North Park and includes relatively low areas of little relief, typical of the basin lowlands, as well as rugged mountainous areas, typical of the surrounding highlands.

The highlands include the east flank and foothills of the Park Range along the western margin of the area; Independence Mountain in the northeastern part; and a narrow highland that includes Sheep Mountain and Delaney Butte and extends southward through the central part of the area as far as the Roaring Fork. These three highland areas merge to the northwest and continue northward into Wyoming as the Sierra Madre. The highest elevations are at the west margin of the area along the flank of the Park Range; they reach about 11,600 feet on Bear Mountain and at a point about 1 mile northwest of Blue Lake. The crest of the Park Range lies about 2½ miles west of the mapped area: Mount Zirkel, the highest peak in the range, lies west of Blue Lake and is 12,180 feet high. The topography along the flank of the Park Range is generally rugged owing to sculpture by mountain glaciers. An almost continuous apron of glacial till forms a relatively low but rough area along the base of the mountains. The Independence Mountain highland and the Sheep Mountain-Delaney Butte highlands are generally lower than the Park Range; elevations reach 9,796 feet on Independence Mountain, 9,422 feet on Sheep Mountain, and 9,307 feet on Delaney Butte. These elevated areas are locally rugged, as on Delaney Butte and the west face of Sheep Mountain, but for the most part they have a relatively subdued topography.

The lowland areas in general have little relief. Their elevations range from about 8,000 feet in the east-central part of the area to about 8,600 feet in the northern and western parts. The lowest point in the area is at an elevation of about 7,930 feet in the valley of the North Platte River at the east boundary of the area. A few low hills such as Battle Ridge, Dead Horse Hill, Peterson Ridge, and Pitchpine Mountain are prominent landmarks in the lowland area.

Relatively flat, parklike areas are contained within walls of lateral and terminal moraines in several of the glaciated valleys. The larger of these areas are in the valleys of the South Fork of Big Creek (Big Creek Lakes area), Roaring Fork, and Norris Creek (Livingston Park).

A small lowland area northeast of Independence Mountain in the extreme northeastern part of the area is a southern arm of the Saratoga Valley. It is the only lowland area of Jackson County not usually considered to be a part of North Park.

DRAINAGE

All northwestern North Park is drained by the north-flowing North Platte River. The North Platte rises in the extreme southeast corner of the area, at the junction of Grizzly and Little Grizzly Creeks, and is joined within the map area by two main perennial tributaries, the Roaring Fork and the North Fork. Two other tributaries that drain large parts of the map area, South Fork of Big Creek and Beaver Creek (Pearl quadrangle), join the North Plattee to the north in Wyoming. All these streams rise in the Park Range or its foothills and supply abundant water to the lowlands through an extensive network of irrigation ditches. Lake Creek, a tributary of the North Fork, drains part of the high area between Independence Mountain and the Park Range and also receives much additional water diverted by an irrigation ditch from the South Fork of Big Creek drainage area. The northeast flank of Independence Mountain is drained by small streams emptying into the North Platte east of the area or in Wyoming.

A series of lakes—including Boettcher Lake, Lake John, and the Delaney Lakes—occupy poorly drained or closed depressions in the lowlands just east of the Sheep Mountain-Delaney Butte highland. Glaciated areas flanking the Park Range contain numerous lakes; most of them are small. The Big Creek Lakes in the northwestern part of the area are the largest of these glacial lakes.

CLIMATE AND VEGETATION

Northwestern North Park has a cool semiarid to moderately moist climate. The relatively high elevation of the area results in long cold winters and fairly short cool summers. The average temperature for the month of January 1957 at Walden, 5 miles east of the area (fig. 1) was 13°; the average temperature for July was 59° (Glantz, 1958, table 1). There were only 61 consecutive frost-free days at Walden in 1957 (Glantz, 1958, table 3). Precipitation varies considerably. The average annual precipitation at Walden is about 9 inches, but at Pearl, in the northwestern part of the area, the average annual precipitation was about 22½ inches for the years between 1910 and 1930 (Martin, 1933, p. 15). Precipitation in the Park Range is probably even greater. A few of the high cirques in the Park Range contain permanent snowfields.

Vegetation in the dry lowlands is mainly sagebush and sparse grass. In stream valleys and irrigated areas, grass used for grazing and for hay grows abundantly. Scrub willows are fairly abundant along many of the streams and irrigation ditches. The lower flanks of the highland areas support a mixed growth of aspen and conifers. The higher parts of the highland areas support a heavy forest of conifers.

INDUSTRY

Stock raising is the principal occupation of the area. Much timber has been cut in the past, and the lumbering potential is large; but current (1962) production is sporadic and has been limited to the Pearl area in recent years. Irrigation produces abundant grass used for grazing and for hay. No other crops are grown due to the short growing season. No minerals are produced at the present time (1962), although in the past, small amounts of coal, copper, fluorspar, and gold have been mined. Fishing, hunting, and camping facilities attract a considerable number of tourists. There are no towns in the area. Pearl, a former copper mining camp, was settled shortly after 1900 but is now virtually abandoned. Walden, the Jackson County seat, whose population is about 900 (1962), is 5 miles east of the area.

ACCESSIBILITY

Good graded roads make most of the lowland parts of the area easily accessible. State Highway 14, connecting U.S. Highway 40 at Muddy Pass with Walden, crosses the extreme southeast corner of the area. Other State highways connect Walden with Granby to the south, Laramie, Wyo., to the northeast, and Saratoga, Wyo., to the northwest. A branch line of the Union Pacific Railroad connects Walden and other points east of the area with Laramie, Wyo. Access to the mountainous areas is mostly by foot and horse trails Only two graded roads give access to the Park Range foothills: one of these leads to the Big Creek Lakes area in the northwest, the other leads to the mouth of Lone Pine Creek canyon at the west-central margin of the area.

PRECAMBRIAN CRYSTALLINE ROCKS

The Precambrian rocks in the area were not studied in detail; they are, however, very complex and include many kinds of metamorphic and igneous rocks. As a result of rapid reconnaissance, these rocks were divided into metamorphic rocks consisting mostly of hornblende and felsic gneisses and granitic rocks, mostly quartz monzonite but ranging in composition from granite to diorite. The spatial relations between the two groups of rocks are complex but were not investigated closely and are represented on the map only in generalized form. The gneisses are in general tightly and intricately folded, but only the dominant trend of the foliation is represented by symbols on the geologic map.

Hague (Hague and Emmons, 1877, p. 130–141) described the Precambrian rocks of the Park Range adjacent to North Park and classified them as granites, micaceous and hornblendic gneisses and schists, and syenites and diorites. In reports on the copper deposits near Encampment, Wyo., and Pearl, Colo., Spencer (1903, 1904) described the Precambrian rocks of the northern Park Range and the southern

Sierra Madre. He (1904, p. 17, pl. 2) reported that the Precambrian rocks of the Sierra Madre include the following: Metavolcanic hornblende schists; metasedimentary quartzite, slate, limestone, and conglomerate; and igneous quartz diorite, granite, and gabbro; as well as gneissic rocks metamorphosed from the igneous rocks. He mapped the rocks near the Colorado-Wyoming State line as granite and hornblende schist and mapped those of the Pearl area (Spencer, 1903, p. 163–164) as banded red and gray granite locally containing much mica and hornblende and as gneissic diorite and pegmatite. Read (1903) briefly described various mineral occurrences in schists in the Pearl area. Steven (1954, 1957, 1960) made a detailed study of the Precambrian and other rocks in the nearby Northgate district, where the Precambrian rocks consist of a gneiss complex cut by younger intrusive igneous rocks.

METAMORPHIC ROCKS

Metamorphic schist and gneiss are the principal Precambrian rocks exposed in the northern one-third of the area. They make up most of Independence Mountain and the flank of the Park Range as far south as Lone Pine Creek. In the highland of the thrust-fault belt extending southward through the central part of the area, metamorphic rocks crop out intermittently as far south as the northern part of Sheep Mountain. South of these areas, metamorphic rocks are found at a few places in small isolated patches that presumably are xenoliths within the intrusive quartz monzonite; most of these are patches too small to be shown on the geologic map. On Independence Mountain and in the highland in the central part of the Pearl quadrangle, the resistant metamorphic rocks form hills that stand above adjacent lowlands formed on the sedimentary rocks; but the upland surface is not particularly rugged except along the Park Range where glaciers have locally sculptured the metamorphic rocks into steep-sided cirques, deep canyons, and sharp peaks.

Steven (1957, p. 338–364) distinguished seven rock types in the metamorphic complex in the Northgate district just east of the report area: hornblende gneiss, quartz monzonite gneiss, biotite-garnet gneiss, pegmatite, hornblende-biotite gneiss, mylonite gneiss, and rheomorphic quartz monzonite gneiss. Most of these types are present in the metamorphic complex of northwestern North Park, but felsic gneiss of granitic and quartz monzonitic composition (fig. 2) and hornblende gneiss predominate. Pegmatite is fairly abundant. The felsic gneiss is composed of quartz, microcline, oligoclase, and minor biotite. Quartz is abundant and makes up about 1/4 to 1/2 of the rock. The rock is predominantly light pink to pinkish gray but is darker

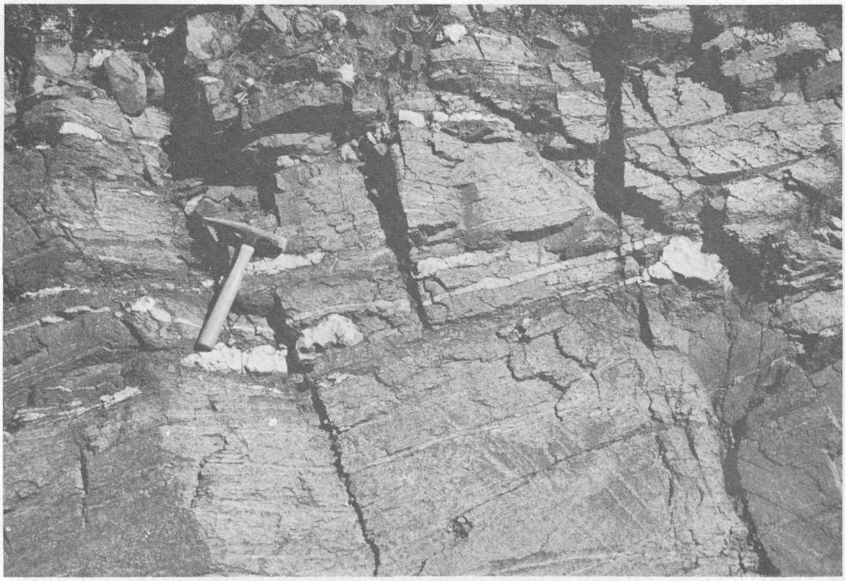

FIGURE 2.—Layered felsic gneiss, exposed in bank along road, 2 miles southwest of Pearl.

where it contains abundant biotite. It is fine to coarse grained, but most of it is medium grained. The pegmatite bodies are of about the same composition as the felsic gneiss and differ from it chiefly in grain size; the larger crystals in the pegmatite are an inch or two in length. The hornblende gneiss is composed mainly of hornblende and andesine in varying proportions. The colors range from light gray to black depending on the content of hornblende. The hornblende crystals are commonly oriented parallel to one another, and the rock is conspicuously layered. The hornblende gneiss is generally medium grained.

The various rocks of the metamorphic complex intergrade and include many varieties intermediate between the major rock types. Steven (1957, p. 338) concluded that metamorphism in the Northgate district transformed an originally layered sequence of rocks into hornblende gneiss, which later was transformed into biotite- and quartz-bearing gneiss and schist and into quartz monzonite gneiss and pegmatite. Presumably, the same conditions of metamorphism formed the metamorphic complex of northwestern North Park. According to Ogden Tweto (oral commun., 1961) hornblende gneisses—many of them garnetiferous—are more abundant in the northern Park Range than in most Precambrian terranes of Colorado, and in the Lone Pine Creek and Bear Creek drainages these gneisses have apparently been incompletely converted to granitic rock in the manner described by Steven.

INTRUSIVE ROCKS

Igneous rocks intrude the metamorphic complex in the Park Range along the west margin of the area from Lone Pine Creek southward to the southern boundary of the area, and they also form Delaney Butte and the southern two-thirds of Sheep Mountain. Like the metamorphic rocks, the intrusive rocks form resistant highlands. Valleys which have been cut into intrusive rocks in the Park Range exhibit rugged cirque and canyon topography, but many of the surfaces of the intervening divides have a relatively gentle topography. Precipitous cliffs mark fault scarps on the east and west flanks of Delaney Butte and the west flank of Sheep Mountain.

Petrographic examination of eight representative samples of the igneous rock shows them all to be quartz monzonite, composed of roughly equal parts of quartz, oligoclase, and microcline, and minor biotite. Accessory minerals are scarce. The rock averages 35 percent quartz, 32 percent oligoclase, 28 percent microcline, and 5 percent biotite. Most of the sampled rocks are medium grained and all exhibit a typically granitic texture. Much of the oligoclase is considerably altered to sericite. In a study of a generally similar quartz monzonite in the Northgate district, Steven (1957, p. 370–372) concluded that an original dioritic or quartz dioritic rock was altered to quartz monzonite by deuteric solutions rich in alkalies and silica.

The intrusive quartz monzonite in fresh outcrops is mainly shades of pink and red, becoming grayish where more than average amounts of biotite are present. The weathered rock is mostly brownish red to brown. The contact between the intrusive rocks and the metamorphic rocks is only locally well exposed, but where it can be seen it is sharp; the intrusive body clearly crosscuts planar or linear structures in the gneiss. There appears to be little alteration of the wall rock at the contact, and in general there are no changes in texture in the intrusive rock, except that small intrusive dikes grade from medium grained at their centers to fine grained at their margins owing to chilling.

Minor bodies of metamorphic rock, the most conspicuous of which are hornblende gneiss, are found within the mass of intrusive rock and are interpreted as xenoliths. Steven (1957, p. 368–370) postulated that the magma from which the intrusive rock in the Northgate district formed was emplaced by piecemeal magmatic stoping controlled by directions of weakness in the wallrocks. A similar mode of emplacement is likely for the intrusive rocks of northwestern North Park.

SEDIMENTARY ROCKS

The sedimentary rocks of northwestern North Park range in age from Permian to Quaternary. The geologic maps (pls. 1, 2, 3) show

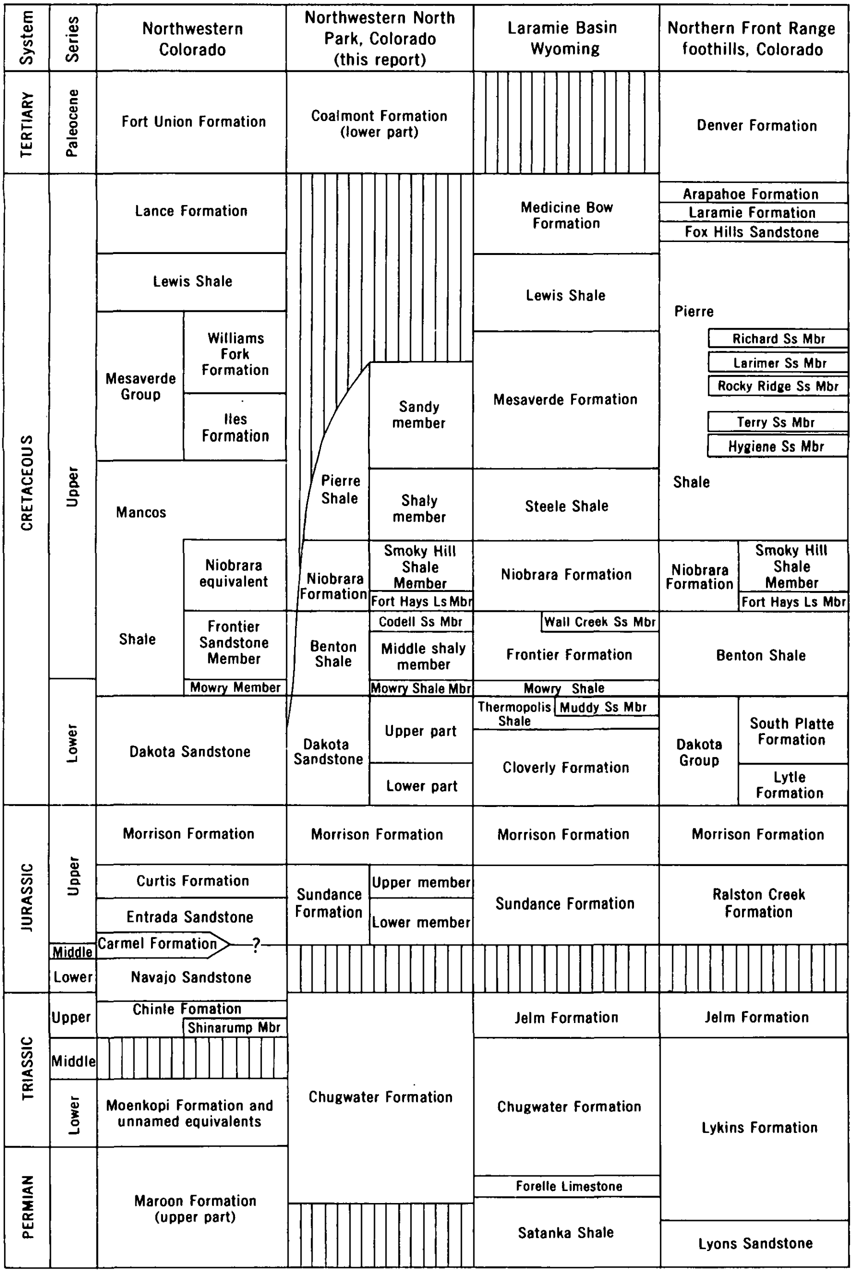

FIGURE 3.—Correlation of pre-Tertiary sedimentary rocks, northwestern North Park and nearby areas.

the areal distribution of these rocks. Figure 3 shows the correlation of the pre-Tertiary sedimentary rocks with rocks in nearby areas.

The North Park–Middle Park structural basin coincides with the axial part of a segment of the so-called ancestral Rocky Mountains or Front Range highland, an area of north-central Colorado that was intermittently structurally positive during most of the Paleozoic resulting in the absence of all sedimentary rocks older than latest Permian either because of erosion or nondeposition.

The maximum thickness of the pre-Quaternary sedimentary rocks in northwestern North Park is about 17,000 feet. A summary of the lithology and thickness of the pre-Tertiary rocks in the area is shown on plate 4.

Pre-Tertiary sedimentary rocks crop out as two wide generally north-trending bands separated by the Sheep Mountain–Delaney Butte highland. The eastern outcrop band extends from Independence Mountain southward to the Roaring Fork. The western band extends from the headwaters of the North Fork of the North Platte River southward to the southern boundary of the area, but along the flank of the Park Range it is partly obscured by glacial drift. Pre-Tertiary sedimentary rocks also crop out in a faulted area on the northeast side of Independence Mountain, in the vicinity of Threemile Creek and Parsons Draw.

Tertiary rocks crop out in the northern part of the area, mostly east of the Sheep Mountain–Delaney Butte highland; smaller outcrops are present on the west side of Sheep Mountain and of Delaney Butte, in the vicinity of Pearl in the northwestern part of the area, on top of Independence Mountain, and in the lowland area northeast of Independence Mountain. South of the Roaring Fork the Tertiary rocks extend westward for several miles almost to the flank of the Park Range.

Quaternary glacial drift occupies a fairly broad band along the lower flank of the Park Range at the west margin of the area. Other Quaternary surficial deposits are scattered throughout the area.

The sedimentary rocks are mostly nonresistant and, in large areas, are covered by a thin mantle of soil or wash. Good exposures are scarce, but a few resistant limestone, sandstone, and conglomerate beds generally form hogback ridges. Areas covered by glacial till generally show a typically rough topography.

A confusing multiplicity of geologic names has been applied by various workers to the sedimentary rocks in North Park. Geologic names have been introduced from northeastern Colorado, from southern Wyoming, and from northwestern Colorado. Names used in this report are modified from those used in U.S. Geological Survey reports on North Park by Beekly (1915) and Steven (1954).

PERMIAN AND TRIASSIC SYSTEMS

CHUGWATER FORMATION

Definition.—Darton (1904, p. 397–398) proposed the name Chugwater for red beds in eastern Wyoming and northern Colorado lying between the Tensleep Sandstone of Pennsylvanian age and the Sundance Formation of Jurassic age. The application of the name Chugwater since that time has been restricted in many ways by various geologists who have traced other named stratigraphic units into the Chugwater sequence or who otherwise subdivided the formation. The name is still in common use throughout southern Wyoming but is not commonly used in Colorado outside of North Park.

The name Chugwater is used in this report to designate the predominantly red-bed sequence lying between the Precambrian crystalline rocks and the base of the Sundance Formation. The formation includes beds in its lower part that are possibly equivalent to the Satanka Shale and the Forelle Limestone, both of Permian age (Beekly, 1915, p. 21–22; Steven, 1954; 1960, p. 335–338); and in its upper part it includes beds equivalent to the lower part of the Jelm Formation of Late Triassic age. Beds possibly equivalent to the Satanka and Forelle are too thin to differentiate on the geologic map, the aggregate being less than 10 feet in thickness. The contact between the Jelm equivalent and lower beds in the Chugwater cannot be clearly seen in the area; therefore, the Jelm equivalent is mapped as part of the Chugwater.

Thickness.—The Chugwater Formation in northwestern North Park ranges in thickness from about 860 feet in the northern part of the area to an estimated 700 feet in the southern part. Only about 230 feet of Chugwater is present in the Hiawatha Oil Co. Government 25, test hole 1 in sec. 25, T. 7 N., R. 81 W. about 5 miles south of the area; even farther south in central Middle Park the Chugwater is absent (Tweto, 1957, p. 20). Southward thinning of the Chugwater probably is mainly due to depositional pinchout of the lower beds against the so-called Ancestral Rocky Mountains. The possible Forelle equivalent near the base of the formation is absent south of sec. 7, T. 11 N., R. 81 W. The extent of thinning of the Chugwater by erosion of the upper beds is not known. Beds of the Jelm equivalent at the top of the formation are present at least as far south as Lake John, but father south the exposures of the Chugwater are too poor to determine whether or not Jelm equivalent beds are present.

Distribution and topographic expression.—The most extensive outcrop of the Chugwater Formation is an almost continuous band, 1/4 to 1/2 mile wide, extending through the central part of the area from the south end of Sheep Mountain northward to the head of Troutman Draw. This outcrop band generally occupies a valley which is cut on soft and easily eroded beds of the Chugwater, Sundance, and Morrison Formations and which is bordered by resistant Precambrian crystalline rocks on the west and resistant hogback-forming beds of the Dakota Sandstone on the east. Exposures of the Chugwater along this valley are generally poor, especially of the lower part of the formation, which at many places is covered by debris from the adjacent highland of Precambrian crystalline rocks. A few resistant ledge-forming sandstone beds in the Chugwater crop out in the upper valley of Lake Creek in sec. 8, T. 11 N., R. 81 W.

The Chugwater Formation crops out conspicuously on the northeast side of Independence Mountain south of Waldron Ranch in the valleys of Threemile Creek and Parsons Draw. Along the flank of the Park Range where the Chugwater might be expected to crop out, it is mostly covered by glacial drift or is faulted out. The largest exposure along the Park Range is about a mile north of Butler Creek in the southwest corner of the area. Other exposures of the Chugwater are rather small and scattered. The formation crops out near the north and south ends of Delaney Butte. Small exposures also occur about half a mile south of Red Canyon Reservoir in the west, just north of Lone Pine Creek about 1¼ miles west of the National Forest boundary, and on Monahan Creek near the south end of Bear Mountain. In addition, small patches of Chugwater are exposed as slices along some of the major thrust faults; for example, on the west side of Sheep Mountain, in the upper valley of the North Fork of the North Platte River, and along the south flank of Independence Mountain.

Lithology.—Rocks of the lower part of the Chugwater Formation are mainly marginal-marine beds consisting of nonresistant red sandstone, siltstone, shale, and some limestone and gypsum; the uppermost beds are mainly nonmarine sandstone and conglomerate. The Chugwater lies unconformably on a beveled surface of Precambrian crystalline rocks. Although the contact is poorly exposed or covered throughout most of the area, no coarse-grained or conglomeratic beds were seen in the basal part, and it is assumed that the Precambrian highland upon which the beds of the Chugwater were deposited was an area of little relief, rising moderately to the south.

Possible equivalents of the Satanka Shale and Forelle Limestone occur in the basal 10 feet of the formation in the northern part of the area. The best exposures are near Waldron Ranch in the northeastern part of the area. The possible Satanka equivalent consists of a few feet of shale and siltstone beds indistinguishable from higher red beds in the Chugwater except for their stratigraphic position below the possible Forelle equivalent. The possible Forelle equivalent consists of one to several thin beds of dense hard purple to gray crystalline limestone which is generally less than a foot thick. Overlying the limestone is the main body of the Chugwater, a thick sequence of red beds, consisting of generally even bedded sandstone, siltstone, and shale. The most conspicuous feature of these beds is their red color, modified only by very minor light-green streaking and mottling. Most of the sandstone and siltstone beds are calcareous; the shale and clayey siltstone beds are generally noncalcareous. Bedded gypsum was seen only in a single locality, a prospect pit about 1,000 feet south of Threemile Reservoir in sec. 6, T. 11 N., R. 80 W., where a bed of it 5 feet thick is exposed. This gypsum probably is about 300 to 400 feet above the base of the formation.

The contact between the upper nonmarine beds and the lower marine beds of the Chugwater is obscure but may be unconformable, as suggested by the unconformable relations of equivalent units outside of North Park. These upper beds consist of red, brown, and gray calcareous sandstone and siltstone; brown and purplish-red conglomerate; and minor amounts of red shale and claystone. The conglomerate is somewhat more resistant than adjacent beds, and where exposed, commonly forms a persistent ledge. Its coarse constituents are mostly angular fragments of sandstone, siltstone, and clay, apparently derived from erosion of lower beds of the Chugwater. It also contains sparse fragments of fossil bone and wood and carbonaceous material.

The following stratigraphic section of the Chugwater was measured just west of Battle Ridge in the northern part of the area:

Section of the Chugwater Formation in NE¼ sec. 7 and W½ sec. 8, T. 11 N., R. 81 W.

Sundance Formation:	
Basal part covered.	
Chugwater Formation:	*Feet*
Poorly exposed to covered; probably nonresistant red beds; top covered; contact with overlying Sundance Formation placed at color change from red to brown in surface wash	39
Sandstone, greenish-gray, very fine grained, calcareous	1
Shale, red	6
Sandstone, greenish-gray, very fine grained, calcareous	1
Poorly exposed; upper part is predominantly red shale; lower part is predominantly red clayey siltstone	76
Sandstone, purplish-red, mottled brownishyellow, fine-grained, calcareous, crossbedded; contains sparse chert and glauconite; resistant; forms persistent ledge	2
Siltstone, red, clayey	21
Shale, purplish-red	17
Poorly exposed; appears to be mostly red siltstone and a few claystone beds	40

Chugwater Formation—Continued	*Feet*
Sandstone, greenish-gray to yellowish-gray, very fine grained, calcareous	1
Shale, red, silty and clayey	13
Sandstone, mostly red, mottled green, very fine grained, calcareous, laminated, very hard; makes resistant ledge	1
Shale, red, silty and clayey	29
Siltstone, red, relatively resistant; weathers into small irregular chips	3
Siltstone, red, clayey	1
Shale, red; contains a few silty beds	28
Claystone, red; contains some silty beds	36
Sandstone, grayish-green, very fine grained, calcerous, thin-bedded to laminated, resistant, ledge-forming	1
Shale, red, silty; resistant ledge at top	6
Siltstone, red	1
Shale, mostly red; has a few green streaks; contains a few silty layers	14
Sandstone, red, very fine grained, calcerous, thin-bedded; weathers to smooth slabs about ¼ in. thick	2
Siltstone, red, clayey	5
Sandstone, red, very fine grained, irregularly thin bedded, moderately resistant	5
Siltstone, red, clayey	6
Sandstone, red, very fine grained, calcareous, irregularly thin bedded, moderately resistant	1
Siltstone, red, clayey	1
Sandstone, red, very fine grained, calcareous, irregularly thin bedded, moderately resistant	1
Shale, red; interbedded with red silty shale in lower part	25
Sandstone, red, very fine grained, calcareous, thin-bedded to laminated, hard; forms resistant ledge	1
Shale, red, silty	1
Sandstone, red, very fine grained, calcareous, thin-bedded to laminated, hard; forms resistant ledge	3
Shale, mostly red; lower 3 ft silty and mottled green	22
Sandstone, mostly red, sparsely mottled green, very fine grained, calcareous; forms moderately resistant ledge	7
Shale, red, silty	3
Sandstone, red, very fine grained, calcareous, thin-bedded, ledge-forming	1
Shale, red, silty	5
Sandstone, red, very fine grained, calcareous	10
Poorly exposed to covered; mostly red shale; some nonresistant red siltstone and sandstone	116
Offset along the strike about 0.4 mile to the south	
Poorly exposed in lower part; covered in upper part; mostly red silty and clayey shale; a few thin beds of moderately resistant siltstone and sandstone	48
Siltstone, red, clayey; weathers to form obscure line of chips along hillside	1

	Feet
Chugwater Formation—Continued	
Shale, red	9
Siltstone, red, clayey; weather to form obscure line of chips along hillside	1
Shale, red silty	7
Sandstone, mostly red, sparsely mottled green, very fine grained, calcareous; forms obscure ledge	1
Offset along the strike about 0.2 mile to the north	
Poorly exposed; mostly red silty and clayey shale; minor amounts of siltstone	95
Covered; surface wash is red	68
Poorly exposed; mostly clayey and silty shale; surface wash contains a few hard siltstone chips	52
Covered except lower 5 ft, which contains a bed of limestone not more than 1 ft thick; material is light brownish gray, red stained on weathered surface, and coarsely crystalline; weathers to hard angular pieces as much as 5 in. long that are scattered along line of outcrop; limestone bed is possibly equivalent to the Forelle Limestone	28
Total Chugwater Formation	862
Precambrian metamorphic rocks.	

The following stratigraphic section, measured just east of Sheep Mountain, shows the lithology of the upper 100 feet of the Chugwater:

Section of the Chungwater Formation in SE¼ sec. 4, T. 9 N., R. 81 W.

	Feet
Sundance Formation (lower member):	
Sandstone, light-gray, light-yellowish-gray-weathering, fine grained, calcareous to noncalcareous, massive, obscurely crossbedded.	
Chugwater Formation:	
Sandstone, greenish-gray to brownish-gray, fine- to medium-grained, calcareous; contains minor amounts of muscovite and biotite, possibly glauconite, and rock fragments; thin resistant slabby-weathering ledges at 1 ft and 5 ft above base	12
Conglomeratic sandstone and conglomerate, interbedded. Sandstone matrix is purplish red and fine to coarse grained and consists of poorly sorted angular to rounded quartz grains, sparse biotite and other dark minerals, calcareous cement, and rock fragments as much as ½ in. long scattered irregularly throughout. Conglomerate occurs in lenticular beds mainly at top and 4 ft below top of unit; it is mostly purplish red, has a few gray streaks, and consists of granules and pebbles that are mostly angular to subrounded fragments of claystone and siltstone less than ¼ in. long and calcareous cement. Entire unit is relatively resistant and forms a persistent ledge	10
Siltstone, red, slightly calcareous, irregularly fissile, thin-bedded to laminated	14
Sandstone, light-gray to white, fine-grained	1
Siltstone, red to purplish-red; upper part fissile	3
Sandstone, light-gray to white, fine-grained, calcareous	2

Chugwater Formation—Continued	*Feet*
Siltstone, red, clayey	6
Sandstone, greenish-gray, white-weathering (some yellow staining near top), calcareous, thin-bedded; contains a few beds of cross-laminated clayey siltstone	47
Poorly exposed; mostly red, clayey siltstone	5+
Partial thickness, upper part Chugwater Formation	100+

Correlation.—No fossils were found in the Chugwater Formation except for sparse fragments of bone and wood in the conglomerate of the upper part of the formation. Correlations are made chiefly on the basis of lithology and stratigraphic position.

The presence of rocks possibly equivalent to the Satanka Shale and Forelle Limestone (Beekly, 1915, p. 21–22; Steven, 1954, 1960, p. 335–338) indicates that the lower part of the Chugwater is possibly Permian. Thomas (1934, p. 1659–1690, figs, 3, 5) traced Permian and Triassic units from western Wyoming to southeastern Wyoming and showed that the Forelle Limestone intertongues with the Phosphoria Formation (Permian) and that younger beds in the lower part of the Chugwater interfinger with the upper part of the Phosphoria Formation and with all of the Dinwoody Formation (Lower Triassic).

As rocks of Middle Triassic age are absent in the Rocky Mountain area, or at least have not been identified on the basis of fossils (Heaton, 1950, p. 1679; McKee and others, 1959, p. 12), it is unlikely that Middle Triassic beds are represented in the Chugwater of northwestern North Park.

The uppermost conglomerate-bearing beds of the Chugwater Formation are equivalent to the lower part of the Jelm Formation as defined by Knight (1917) at Jelm Mountain, Wyo., about 25 miles northeast of the mapped area and to the Jelm Formation (restricted) of Pipiringos (1957, p. 9–10) in the same area. In northwestern Colorado, rocks similar in lithology and stratigraphic position to the Chugwater Formation of northwestern North Park include the upper part of the Maroon Formation (equivalent to the Park City Formation of Permian age), Moenkopi Formation and unnamed equivalents, and the Chinle Formation of Late Triassic age. East of North Park, in the northern foothills of the Front Range in north-central Colorado, equivalents of the Chugwater are probably represented by the Lykins and Jelm Formations.

The only identifiable fossils found in the Chugwater are wood fragments of probable Late Triassic age from the conglomerate at the top of the formation about 1½ miles north of Boettcher Lake in the SW¼ sec. 8, T. 10 N., R. 81 W. These specimens were identified by R. A. Scott who stated (written commun., 1959):

The specimens represent *Araucarioxylon*, the wood of conifers belonging to the family Araucariaceae. The wood is recrystallized, and the preservation leaves something to be desired; however, it appears to be assignable to *A. arizonicum*, the araucarian wood so abundant in the Chinle Formation. This resemblance strongly suggests, but is not adequate to confirm, a late Triassic age for the material.

JURASSIC SYSTEM

SUNDANCE FORMATION

Definition.—The Sundance Formation was named by Darton (1899, p. 387–393) for exposures near the town of Sundance, in the Black Hills, Wyo. The name is widely used in eastern Wyoming to designate rocks of Late Jurassic age that generally underlie the Morrison Formation, also of Late Jurassic age, and overlie various formations of Middle and Early Jurassic and Triassic age. The name Sundance is not commonly used in Colorado outside North Park.

As used in this report the Sundance Formation includes the strata lying between the Chugwater Formation and the Morrison Formation. This corresponds to the usage by Steven (1954; 1960, p. 340) in the Northgate district in northeastern North Park. Beekley (1915, p. 26–28) did not recognize the Sundance in North Park and included these strata in the Morrison Formation. The Sundance is informally divided into a lower member and an upper member.

Thickness.—The Sundance Formation in northwestern North Park ranges in thickness from about 100 to 150 feet. It is thickest in the outcrop area between Sheep Mountain and Lake John; it is thinnest in the Kirk Johnson Big Horn Ranch 1 test hole in the NW¼ sec. 27, T. 10 N., R. 81 W., and in the Carter Oil Co. Government-McDannald 1 test hole in the SE¼ sec. 4, T. 10 N., R. 80 W. Thickness measurements of the Sundance are not readily obtainable because the base of the formation is commonly covered.

Distribution and topographic expression.—The Sundance Formation is nonresistant and is generally poorly exposed. It crops out in a fairly continuous thin band in the central part of the area, from a point near Brands Ranch just west of Lake John northward to the north end of Battle Ridge. In this area, it generally lies along the base of a hogback capped by rocks of the Dakota Sandstone and is commonly obscured by talus and wash from these overlying rocks.

It is seen chiefly in gullies. Where the lower part is better cemented than usual, it forms moderately resistant rounded outcrops. The upper member of the formation is fairly well exposed just south of the junction of Spring Gulch and Hell Creek in the south-central part of the area.

Lithology.—The lower member of Sundance Formation consists entirely of sandstone. The contact with the underlying Chugwater Formation is probably unconformable, as suggested by the unconformable relation of the formations in the Northgate area of North Park, about 6 miles east of this area (Steven, 1954; 1960, p. 338) and of equivalent units outside North Park. The basal contact was seen clearly at only one locality in the area, just east of Sheep Mountain in the NE¼ sec. 4, T. 9 N., R. 81 W. where there is an abrupt change in lithology across the contact. Clean light-gray fine-grained sandstone of the Sundance lies on greenish- to brownish-gray rather poorly sorted sandstone of the Chugwater.

The lower member of the Sundance is a remarkably homogeneous unit, ranging in thickness from about 70 to 120 feet. The sandstone is clean fine grained and mostly light gray to white; locally, it is pink and rusty brown in the uppermost 2 feet. It is mostly very friable but is firm and resistant where cemented by calcium carbonate. The unit appears to be massive; bedding is generally not apparent, although obscure crossbedding may be seen on some surfaces, and the uppermost foot or two is even bedded. Conspicuous crossbedding has been observed in this unit in the Northgate area of North Park (Steven, 1954; 1960, p. 340) and in the southwestern part of the Laramie Basin (fig. 1) (Lee, 1927, p. 15; Heaton, 1939, p. 1158; Pipiringos, 1957, p. 17–19).

Overlying the lower member is a sequence of interbedded sandstone and shale, whose contact with the lower member is marked by a fairly abrupt change in lithology and whose thickness ranges from 30 to 45 feet. Marine invertebrate fossils and glauconite in this unit mark it as marine in origin. The sandstone beds in the upper member are mostly even bedded, gray to grayish green, very fine to medium grained, and calcareous. The shale is mostly gray to green, locally mottled red, and calcareous. The lower part of the member contains a distinctive bed of lenticular or nodular sandstone containing casts of possible worm burrows. A thin layer of orange chert or chalcedony intergrown with crystalline calcite apparently of epigenetic origin occurs irregularly in the upper part of the member about 10 to 15 feet below the top. Glauconite in the upper part of the Sundance Formation occurs most abundantly in the northern part of the area in a bed that G. N. Pipiringos (oral commun., 1957) believed may correlate with the Redwater Shale Member of the Sundance in Wyoming. A green mineral, possibly glauconite, occurs in the nodular sandstone containing the possible worm-burrow casts.

The following stratigraphic section of the Sundance was measured on the west slope of Battle Ridge in the northern part of the area:

Section of Sundance Formation in NW¼ sec. 8, T. 11 N., R. 81 W.

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

	Feet
Morrison Formation:	
Limestone, light-gray, thin-bedded; weathers to hard dense ledge-forming slabs; contains a bed 1 in. thick of red and green claystone at base.	
Sundance Formation:	
Upper member:	
Sandstone, light-gray to light-greenish-gray, fine-grained, calcareous, thin-bedded; weathers slabby; contains a massive nonresistant bed about 8 in. thick near middle of unit	3
Offset along the strike about 600 ft to the north	
Siltstone and shale interbedded, sandy and clayey, calcareous; contains abundant glauconite; upper part predominantly shaly; lower part predominantly sandy and silty; sand is medium to coarse	11
Siltstone, light-greenish gray, clayey, calcareous, nonresistant	2
Shale, mostly grayish-green (red and green mottling in lower part), silty, calcareous; contains a sparse green mineral that is possibly glauconite, lenticular sandstone nodules resembling worm-burrow casts, and fossil marine pelecypods *Camptonectes tancredia*(?)	7
Claystone, mostly grayish-green (minor red and green mottling), silty, slightly fissile, calcareous; basal 2 ft sandy	8
Sandstone, pinkish-gray to grayish-white, fine-grained, calcareous, massive; upper 1 ft slightly clayey; lower 1½ ft greenish gray, shaly	4
Lower member:	
Poorly exposed to covered; appears to be mostly sandstone, yellowish-white to light-gray (pink at top), fine-grained, calcareous, very friable; bedding not apparent	60
Covered; contact with underlying Chugwater Formation placed at color change from brown to red in surface wash; thickness approximate	±25
Total Sundance Formation	±120
Chugwater Formation:	
Poorly exposed to covered; probably nonresistant red beds.	

The following stratigraphic section of the Sundance was measured just east of Sheep Mountain in the central part of the area:

Section of the Sundance Formation in NE¼ sec. 4, T. 9 N., R. 81 W.

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

	Feet
Morrison Formation:	
Sandstone, light-green, silty to fine-grained, calcareous.	
Sundance Formation:	
Upper member:	
Sandstone, white, light-yellowish-brown to grayish-brown-weathering, fine-grained, calcareous, thin bedded; weathers to thin slabs; minutely ripple marked	5
Shale, dark-grayish-green, noncalcareous; interlaminated calcareous siltstone and sandstone beds and nodules; mostly shaly in lower part; sandy in upper part	2
Sandstone, light-gray, fine-grained, calcareous, even bedded, ripple-marked, resistant, ledge-forming; weathers along curved rippled-marked bedding surfaces	1
Sandstone, yellowish-gray, very fine grained to silty, calcareous, obscurely even bedded; basal 6 in. is shaly greenish-gray siltstone that is cherty in the basal 1 in	10
Shale, light to medium-greenish-gray, silty; contains sparse to abundant green mineral, possibly glauconite; except for basal 1 ft, contains abundant sandy nodules resembling worm-burrow casts; nodules contain clay pellets	18
Lower member:	
Sandstone, light-gray to yellowish-white, fine-grained; quartzose except for very sparse dark grains and clusters of rusty grains; calcareous to noncalcareous; mainly friable and nonresistant; a few slightly more resistant layers are lime cemented; massive to obscurely crossbedded; upper 1 to 2 ft weathers to rusty yellowish brown	116
Total Sundance Formation	152
Chugwater Formation:	
Sandstone, greenish-gray to brownish-gray, fine- to medium-grained, calcareous; contains minor amounts of muscovite and biotite, possibly glauconite, and rock fragments; thin bedded; weathers to slabs.	

Correlation.—The lower member of the Sundance Formation contains no fossils, and the correlation of this unit with rocks of similar stratigraphic position elsewhere is not entirely clear. Heaton (1939, p. 1158) and Pipiringos (1957, p. 15–16) showed that the lower sandstone constitutes a part of the original Jelm Formation as defined by Knight (1917). The lower member is undoubtedly the same unit that Lee (1927, p. 15–16) variously referred to as the basal sandstone member, the lower sandstone member, or the crossbedded sandstone member of the Sundance. The unit is commonly recognized throughout eastern Wyoming. Pipiringos (1957, p. 19) believed that the unit may include the Canyon Springs Sandstone Member of the Sundance in southwest Laramie Basin, Wyo. Lee (1927, p. 16) recognized the basal sandstone unit as far south as Morrison, Colo., about 90 miles south of the Wyoming State line along the Front Range. In the Front Range area the sandstone unit is commonly included with the Morrison Formation. In the Golden, Colo., area it is the basal unit of the Ralston Creek Formation (Van Horn, 1957).

Correlation of the lower sandstone with rocks of northwestern Colorado is based mainly on comparison of lithology and stratigraphic position. The Entrada Sandstone is lithologically similar to the lower member in North Park, and the two may be equivalent. Correlation with the Entrada is based on the assumption that rocks of Early and Middle Jurassic age are absent in North Park.

The upper member of the Sundance Formation is readily correlated with similar strata throughout northern Colorado and Wyoming.

Rollins[1] and Wakefield[2] recognized marine beds of the Sundance and reported the fossil marine pelecypods *Astarte packardi* White and *Camptonectes* sp. from a locality in the NW¼ sec. 17, T. 10 N., R. 81 W.

The nodular sandstone that contains distinctive markings of possible worm-burrow casts is sparsely fossiliferous in much of its outcrop area. Fossils collected from this bed in the NW¼ sec. 8, T. 11 N., R. 81. W. were examined by R. W. Imlay, who stated (written commun., 1957):

> The marine fossils * * * include *Camptonectes tancredia?* and some cap-shaped organic structure. The pelecypod genera range into the Cretaceous, but in the western interior *Camptonectes* has never been found in the Cretaceous. The species of *Camptonectes* present is much smaller than most of the described species from the Sundance Formation, but I doubt whether its size has stratigraphic significance. There is no question about the beds being marine.

Fossils from the upper part of the Sundance Formation in the Northgate area of North Park, about 6 miles east of the area, include *Trigonia quadrangularis* Hall and Whitfield, *Trigonia* aff. *T. sturgisensis* Whitfield and Hovey, *Tancredia* sp., and *Quenstedia* sp. (Steven, 1960, p. 340).

Pipiringos (1957, and oral commun., 1957) traced the Sundance Formation and adjacent formations from central Wyoming through

[1] Rollins, J. F., 1952, Stratigraphy and structure of the Sheep Mountain area, Jackson County, Colorado: Nebraska Univ. unpublished Master's thesis.

[2] Wakefield, L. W., 1952, Geology of the Boetcher Ridge-Sheep Mountain-Delanos Butte area, North Park, Colorado: Colorado Univ. unpublished Master's thesis.

the Laramie Basin to northwestern North Park and was able to identify in the upper member in northwestern North Park probable equivalents of his member A, the Redwater Shale Member, and his member B. The upper member of the Sundance of northwestern North Park is correlated with the Curtis Formation of northwestern Colorado mainly on the basis of similar age, lithology, and stratigraphic position.

MORRISON FORMATION

Definition.—Cross (1894) first used the name Morrison for rocks exposed near Morrison, Colo. Although there has been some question regarding both the upper and lower boundaries of the Morrison, the name, as now used, generally denotes Upper Jurassic nonmarine beds, overlying Upper Jurassic marine beds of the Sundance or Curtis Formations or their equivalents (Imlay, 1952, chart 86) and underlying Lower Cretaceous beds of the Dakota Sandstone or Cloverly Formation or their equivalents (Cobban and Reeside, 1952, chart 10B). The name Morrison is used over a very large area of Colorado, Wyoming, Montana, Utah, Arizona, and adjoining States.

In this report, the name Morrison designates the nonmarine rocks conformably overlying the marine rocks of the Sundance Formation and unconformably underlying the rocks of the Dakota Sandstone. Beekly (1915, p. 26–29) mapped the Morrison Formation in North Park but included in its lower part beds which are here included in the Sundance Formation.

Thickness.—The Morrison Formation in northwestern North Park ranges in thickness from about 310 to about 430 feet. It is thickest near the southwest corner of the area in secs. 22 and 27, T. 8 N., R. 82 W. It is apparently thinnest in the Carter Oil Co. Government-McDannald 1 test hole in sec. 4, T. 10 N., R. 80 W., in the northeastern part of the area. The variation in thickness is probably due to differential erosion of the upper beds prior to deposition of the Dakota Sandstone.

Distribution and topographic expression.—Although the Morrison Formation is relatively nonresistant, it is fairly well exposed at places throughout the area, because it occupies the back slopes of hogback ridges formed by resistant sandstone beds of the Dakota. Lenticular sandstone beds in the lower part of the formation are locally resistant, but the top of the formation is commonly obscured by blocks and rubble of the overlying conglomeratic sandstone of the Dakota. It crops out in an irregular but almost continuous band in the central part of the area from a point just west of the south end of Lake John, northward to the north end of Battle Ridge. It also crops out along the west slope of the hill that extends southward for about 1 mile from the junction of Spring Gulch and Hell Creek in the south-central part of the area. The Morrison crops out at several places in the southwest part of the area, including the crest of Pitchpine Mountain, along the flank of the Park Range about 2 miles west of Pitchpine Mountain, in the extreme southwest corner of the area, and at other scattered localities.

Lithology.—The Morrison Formation in northwestern North Park consists of gray, green, and red claystone and siltstone; brown to gray sandstone; and minor amounts of clay-pebble conglomerate and limestone. The coarser clastic beds are generally calcareous; the claystone beds are generally noncalcareous. The basal contact of the Morrison is placed at the base of a discontinuous thin bed of limestone. The contact with the underlying Sundance Formation probably is almost everywhere conformable. The lithology of the Morrison Formation in northwestern North Park is compatible with the commonly accepted belief that the depositional environment was that of a broad low flood plain.

The Morrison Formation may be roughly divided into two units. The lower unit includes about two-thirds of the formation and consists of nonfissile gray, green, and red claystone; siltstone and sandstone; some clay-pebble conglomerate; and the thin limestone at the base. The basal limestone is generally less than 2 feet thick but is hard and resistant, almost lithographic in texture, and forms a ledge. It is locally absent, as in sec. 4, T. 9 N., R. 81 W., just west of Lake John, but is present in most nearby exposures. Many of the claystone beds are silty and grade into clayey siltstone beds. The siltstone beds contain claystone fragments that appear to be detrital, and detrital claystone and siltstone fragments are conspicuous in many of the sandstone beds. In some areas, particularly between Sheep Mountain and Lake John, these coarse detrital constituents are so abundant in the sandstone beds that they are classified as conglomerates. The sandstone beds are, in general, lenticular; where bedding is apparent, they are crossbedded.

The upper unit or upper third of the Morrison Formation is predominantly gray to grayish-green claystone; the conspicuous red colors of the claystone beds in the lower unit of the formation are absent. Sandstone beds are relatively thin and inconspicuous; however, in secs. 22 and 27, T. 8 N., R. 82 W., and in the S½ sec. 27, T. 9 N., R. 81 W., the upper unit contains clay-pebble conglomeratic sandstone beds. Also present in the upper unit are scattered resistant lenses of limestone. Locally, as between Sheep Mountain and Lake John, the uppermost claystone bed is deeply oxidized.

The following stratigraphic section of the Morrison was measured just east of Sheep Mountain in the central part of the area:

Section of the Morrison Formation in SW¼ sec. 3 and NE¼ sec. 4, T. 9 N., R. 81 W.

	Feet
Dakota Sandstone:	
Lytle equivalent:	
Conglomerate, light-brown; crossbedded; sandstone matrix is medium grained; contains chert and some quartzite pebbles; pebbles are subrounded and as much as ¾ in. long; entire unit resistant and makes conspicuous hogback.	
Morrison Formation:	
Claystone, greenish-gray to dark-gray; top 5 ft oxidized orange red to yellow	40
Limestone, light-brown, weathers yellowish white; interbedded with greenish-gray to gray claystone; limestone forms resistant lenses 1 to 3 ft thick within the unit; limestone contains sparse casts of small gastropods filled with calcite crystals; resistant; forms ledge	10
Poorly exposed; mostly greenish-gray to gray claystone and calcareous siltstone	99
Offset along the strike 0.7 mile to the north	
Siltstone, grayish-brown, slightly calcareous	2
Claystone, light-grayish-green	4
Sandstone, light-brown, very fine grained, calcareous, resistant; forms ridge	1
Claystone, light-greenish-gray	12
Sandstone, light-gray, fine-grained, calcareous; fairly abundant fine to coarse claystone and siltstone grains; sparse biotite; obscurely crossbedded, fairly resistant, ledge forming	4
Siltstone, grayish-brown, calcareous	2
Sandstone, light-gray, calcareous, crossbedded	2
Siltstone, greenish-gray, weathers yellow near base; slightly calcareous	8
Conglomeratic sandstone, grayish-brown; yellow weathered zone near middle of unit; matrix is fine- to medium-grained sandstone; contains abundant dark fragments that are mostly chert; weathered surface is knobby; pebbles occur in lenses and disseminated throughout matrix; pebbles are mostly claystone fragments as much as ¼ in. long and smaller dark chert fragments; entire unit is calcareous and crossbedded, resistant, ledge forming	9
Claystone, light-green and dark-red	25
Sandstone, greenish-gray, light-brown-weathering, very fine grained, calcareous, crossbedded	1
Claystone, light-green	4
Sandstone, greenish-gray, light-brown-weathering, very fine grained, calcareous, crossbedded; hard, ledge-forming; weathers along curved crossbedded surfaces	6
Sandstone, greenish-gray; calcareous; contains a few stringers of clay along bedding planes; soft, nonresistant	6
Claystone, light-green and dark-red, silty, calcareous	25

745–100 O—65——3

Morrison Formation—Continued	*Feet*
Sandstone, grayish-brown, very fine grained, calcareous; contains small amount of carbonaceous material; resistant at top; forms obscure ledge	3
Conglomeratic sandstone, light-brownish-gray, light-brown-weathering, calcareous, hard; matrix is very fine to fine-grained sandstone; contains sparse stringers of claystone and carbonaceous film on some bedding planes, numerous black carbonaceous grains, claystone and siltstone fragments, and some carbonaceous material as long as ¼ in.; entire unit is crossbedded, fairly resistant, and ledge forming	8
Claystone, mottled light-green and dark-red, silty, calcareous	7
Sandstone, greenish-gray, brownish gray-weathering, very fine grained, calcareous; contains fragments of light-green claystone; lenticular; forms obscure ledge	2
Claystone, mottled light-green and dark-red, silty, calcareous	10
Sandstone, greenish-gray, brownish-gray-weathering, very fine grained, calcareous; contains sparse fragments of light-green claystone obscurely crossbedded, ledge forming; lenticular	2
Claystone, mottled light-green and dark-red, silty, calcerous	17
Siltstone, light-green, brownish-gray-weathering, calcareous; contains stringers and fragments of light-green claystone; crossbedded, moderately resistant	1
Claystone, light-green, silty, calcareous	4
Siltstone, light-green, weathers brownish-gray; calcareous contains stringers and fragments of light-green claystone; crossbedded	1
Claystone, light-green; sparsely mottled dark red	6
Siltstone, mostly light-greenish-gray (red at top), calcareous, obscurely crossbedded thin resistant beds at top and base	4
Siltstone, greenish-gray; calcareous; contains stringers of light-green claystone; resistant	1
Siltstone, light-green (except lower 3 or 4 ft which is mottled light green and top 1 ft which is dark red), clayey, very fine grained, calcerous, nonresistant	10
Claystone, greenish-gray	6
Sandstone, greenish-gray, very fine grained, calcareous; clayey in upper part soft, nonresistant	7
Claystone, light-green and dark-red; contains a few calcerous silty beds	22
Sandstone, light-green, very fine grained; calcareous; contains a few stringers of light-green claystone; moderately resistant, ledge forming	4
Claystone, mostly dark-red, has some light-green bands	2
Siltstone, light-green, calcareous, resistant, ledge forming	1
Siltstone, light-green, clayey, calcerous, nonresistant	6
Claystone, dark-red, silty, slightly calcareous	2
Claystone, light-green, silty, slightly calcareous	4
Siltstone, greenish-gray, light-brown-weathering, calcareous; contains fragments of light-green claystone; resistant, ledge forming; weathers out in rounded masses; some weathered surfaces contain markings resembling worm-burrow casts	1

Morrison Formation—Continued	Feet
Claystone, gray and dark-red	4
Siltstone, greenish-gray, rusty-brown-weathering, calcareous, nonresistant	6
Siltstone, light-grayish-green, weathers brown; calcareous; contains small fragments and stringers of light-green claystone; calcareous, resistant, ledge forming	4
Siltstone, light-gray, calcareous, nonresistant	6
Sandstone, light-gray, light-brown-weathering; calcareous, obscurely crossbedded, ledge forming	1
Siltstone, yellowish-green, calcareous, nonresistant	1
Total Morrison Formation	413

Sundance Formation:

Sandstone, light-gray, very fine grained, calcareous, thin bedded, ledge forming.

Correlation.—The distinctive lithology and the stratigraphic position of the Morrison Formation in North Park leave little doubt that the formation is correlative with the Morrison as recognized throughout the Rocky Mountain area.

The Morrison Formation is distinguished in some areas for its fossil dinosaurs. In northwestern North Park dinosaur bones are not abundant in the Morrison, but scattered bone fragments are present in some outcrops. Many bone fragments were found about 100 feet above the base of the formation about 1 mile north of Boettcher Lake, in the NW¼ sec. 17, T. 10 N., R. 81 W. One of the fragments was examined by G. E. Lewis, who stated (written commun., 1959):

> Specimen 729 is the partial centrum of the caudal vertebra of a large sauropod saurischian 'dinosaur'. No conclusive determination is possible. Probably one of the genera *Brachiosaurus*, *Camarasaurus*, or *Apatosaurus* is represented. For example: No. 729 corresponds rather closely with certain caudal vertebrae (17th to 21st) of *Camarasaurus* in the Yale and American Museum collections. Whatever the genus may be, No. 729 is a characteristic kind of Morrison faunal element.

Beekly (1915, p. 29) reported finding a few fossils in the Morrison Formation in northwestern North Park. Among these, found in sec. 33, T. 10 N., R. 81 W., were *Unio* sp., *Valvata scabrida* Meek and Hayden, *Planorbis veternus* Meek and Hayden, *Viviparus gilli* Meek and Hayden(?), and reptilian remains including a dermal spine of *Stegosaurus*. Beekly concluded that: "Stegosaurus is found only in the Morrison and, with the invertebrate fossils identified, establishes the Morrison age of the formation beyond question."

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

DAKOTA SANDSTONE

Definition.—Considerable confusion has marked the use of the name Dakota in its application to the sandy Lower Cretaceous beds in northern Colorado and adjacent areas. Waagé (1955, p. 16–18) discussed in considerable detail the history of the Dakota terminology since the name was first used by Meek and Hayden in 1862 (p. 419–421). The name Dakota Group as used in northern Colorado was first applied by Lee (1923, p. 4) and included all the beds between the Morrison Formation and the Benton Shale. (The base of the Benton Shale is correlative with the base of the Graneros Shale of Colorado and with the base of the Mowry Shale of Wyoming.) Steven (1960, p. 343) followed Lee's terminology and used the name Dakota Group in the Northgate district of North Park. Waagé followed Lee's terminology but divided the Dakota Group into two formations, which he called the Lytle—consisting of sandstone, conglomeratic sandstone, and variegated claystone—and the South Platte—consisting of alternating gray to black shale and brown-weathering sandstone (Waagé, 1955, p. 17, 19, 27). According to Waagé (p. 18–19), these two formations are separated by a regional disconformity.

Mapping of the Lytle and South Platte as separate units proved impractical in North Park; therefore these formations were mapped together as the Dakota Sandstone. The base of this sandstone lies unconformably on the Morrison; the top conformably underlies the Benton Shale, which consists in its basal part of platy siliceous shale here assigned to the Mowry Shale Member of the Benton. Beekly (1915, p. 3–34, pl. 12) used the name Dakota Sandstone for the equivalent rocks but apparently placed the upper boundary at the top of the most resistant hogback-forming sandstone bed, which is not the same bed at all places throughout North Park.

Thickness.—The thickness of the Dakota Sandstone ranges from about 170 feet in the measured section 1 mile south of Sheep Mountain to about 235 feet near the south end of Lake John.

The lower part, the Lytle equivalent, ranges from about 60 to about 125 feet in thickness. The minimum thickness of 60 feet was measured at the northernmost outcrop in the area, on Battle Ridge, and was also recorded in the Carter Oil Co. Government-McDannald 1 test hole in the northeast part of the area. The maximum known thickness of about 125 feet was measured just west of the south end of Lake John.

The upper part, the South Platte equivalent, ranges from about 80 to 130 feet in thickness, but the lack of completely exposed sections makes reliable thickness figures difficult to obtain. The upper part is thinnest in a section measured about 1 mile south of Sheep Mountain in sec. 27, T. 9 N., R. 81 W. It is thickest in a section measured at the northernmost outcrop at the north end of Battle Ridge.

Distribution and topographic expression.—Prominent hogback ridges and dip slopes characterize outcrops of the Dakota Sandstone. Sandstone and conglomerate in the Dakota are in general the most resistant sedimentary rocks in the area. The most conspicuous outcrop of the Dakota is the hogback ridge extending northward from a point near the south end of Lake John almost continuously to the north end of Battle Ridge. The Dakota forms the crest and upper slopes of the prominent hill between Sheep Mountain and Delaney Butte in the south-central part of the area. In the southwestern part of the area, the Dakota forms the flanks of Pitchpine Mountain and crops out in a rather extensive area for about 2 miles westward toward the flank of the Park Range. Scattered exposures are found along the flank of the Park Range from the southwest corner of the area as far north as Ute Creek, but for the most part, the Dakota in this area is covered by glacial drift.

Lithology.—The Lytle equivalent, which constitutes the lower part of the Dakota Sandstone, is predominantly nonmarine sandstone, conglomeratic sandstone, and conglomerate, but contains a little vari-colored claystone at the top. The lithology of the Lytle equivalent contrasts markedly with the underlying Morrison Formation, which is mostly claystone; the contact between the two formations at all localities where it is clearly seen is sharp, undulating, and apparently unconformable. The Lytle equivalent lies on truncated beds of the Morrison in the outcrop area near the crest of the hill between Sheep Mountain and Delaney Butte, in sec. 27, T. 9 N., R. 81 W., where as much as 50 feet of clay-pebble conglomerate and sandstone in the upper part of the Morrison is cut out within a distance of about 1,000 feet. Highly oxidized claystone of the Morrison underlies the basal conglomeratic sandstone bed of the Lytle equivalent just west of Lake John.

The most distinctive feature of the sandstone beds of the Lytle equivalent is their content of chert and quartzite pebbles (fig. 4). The pebbles are distributed very irregularly in the standstone. In some beds they are so abundant that the rock is a conglomerate; in other beds they are concentrated in thin lenses and stringers separated by nonconglomeratic layers; in still other beds they are sparse or absent. The larger pebbles are invariably rounded. No local source for the pebbles is known; because such pebbles characterize equivalent beds elsewhere in much of the Rocky Mountain area, they are assumed to

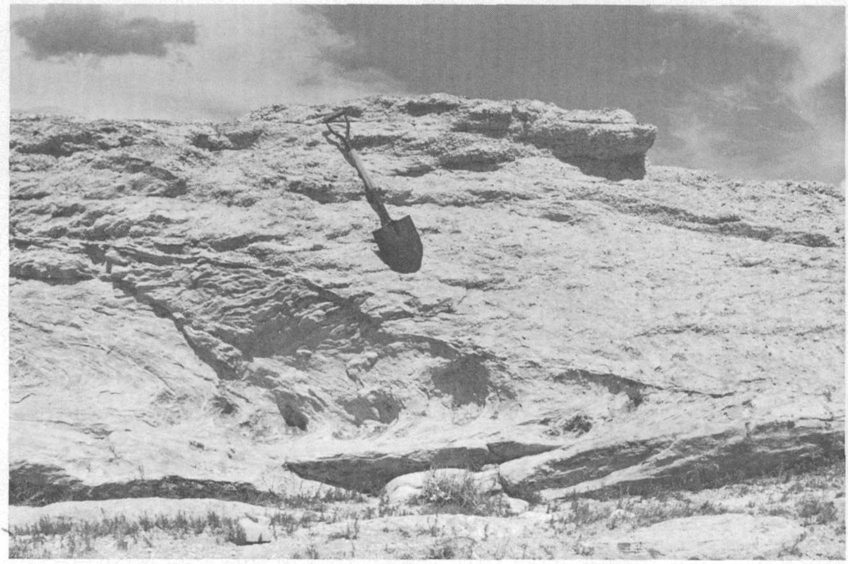

FIGURE 4.—Conglomeratic sandstone in the lower part of the Lytle equivalent of the Dakota Sandstone, in the NE¼ sec. 17, T. 10 N., R. 81 W.

have come from a distant source. The sandstone beds are generally white to very light gray, light brown, and grayish yellow, although a few beds are ferruginous and stained by iron oxides to various shades of red and rusty brown. A chalky white to gray color is imparted to many of the standstone beds by abundant white clay cement. The sandstone beds are variably resistant to erosion, and ridges are formed by different beds of the formation from place to place.

The top of the Lytle equivalent commonly contains claystone beds that are usually light shades of green, gray, and red. The upper claystone beds are inconspicuous because they are commonly covered by debris from adjacent resistant sandstone units.

The South Platte equivalent, which constitutes the upper part of the Dakota Sandstone, consists of marine and marginal-marine sandstone, siltstone, and shale. Carbonized plant fragments and other carbonaceous material are abundant.

The South Platte equivalent may be divided roughly into three units: a lower sandstone, a middle dark shale, and an upper sandstone and siltstone. The lower sandstone unit, about 30 to 45 feet thick, is the most conspicuous of the three, although locally the basal part includes nonresistant sandstone, siltstone, and silty claystone containing streaks of lenses of carbonaceous material or dark shale. The sandstone beds are light gray to brown and in places weather rusty brown to red. The sandstone is even bedded, cross-laminated, very fine to medium grained, and generally very hard and resistant. It forms conspicuous hogback ridges and dip slopes, and in many places, a talus of crudely rectangular blocks. Ripple marks and markings of possible worm-burrow casts are fairly abundant. Carbonaceous material, including leaf and stem fragments, is disseminated throughout the sandstone and also occurs as films along bedding planes. About 8 to 10 miles south of the area, this lower unit contains coaly shale and shaly coal.

The basal contact of the South Platte equivalent is placed at the base of the first bed overlying the varicolored claystone or the conglomeratic sandstone of the Lytle equivalent. Although sandstone predominates, the basal beds of the South Platte equivalent generally contain the lowest dark shale or carbonaceous material in the Dakota Sandstone. The basal contact appears sharp and marks a clear break between the distinctive lithologies of the Lytle and South Platte equivalents.

The middle dark shale unit of the South Platte equivalent is about 20 to 55 feet thick and is soft, nonresistant, and invariably poorly exposed. Commonly, it is eroded off the dip slope formed on the underlying lower sandstone unit. In the few outcrops where it was seen it consists of black to dark-gray shale interbedded with standstone and siltstone. The shale is silty and contains films of carbonaceous material on the bedding planes. The sandstone and siltstone beds are light to dark gray, fairly even bedded, and cross laminated; some beds weather into curved slabs. Carbonaceous material is abundant. Some of the weathered surfaces of the sandstone and siltstone beds contain markings that are possibly worm-burrow casts. Thin beds of bentonite were seen in the section measured near Norris Creek at the south end of Pitchpine Mountain. The middle shale unit increases in thickness from south to north apparently at the expense of sandstone and siltstone beds of the upper unit, which become fewer and thinner northward. At the northernmost outcrop of the Dakota, on Battle Ridge, almost the entire interval between the lower sandstone unit and the overlying Benton Shale is dark shale.

The upper sandstone and siltstone unit of the South Platte equivalent is not greatly different from the middle shale unit except that sandstone and siltstone are more abundant than shale. The sandstone and siltstone beds are highly irregular in thickness, persistence, and resistance to erosion. The sandstone beds are light gray to brown, very fine grained to silty, even bedded, cross-laminated, and commonly weather in crudely rectangular blocks or in thin slabs which have curved surfaces. Carbonaceous material and possible worm-burrow markings are abundant. Some of the beds, particularly in the upper part of the unit, contain fish scales. Some of the sandstone is thoroughly cemented by quartz and could be termed quartzite. Weathered fragments of the quartzitic rock mark the upper part of the South Platte equivalent in covered areas. The upper sandstone unit is thickest and most resistant in the E½ sec. 27, T. 9 N., R. 81 W., on the prominent hill between Sheep Mountain and Delaney Butte. The sandstone here makes the conspicuous outermost hogback ridge on the hill. Northward from this locality the sandstone and siltstone beds of the upper unit become thinner, and finger out into dark shale characteristic of the middle shale unit; and at the north end of Battle Ridge in the northern part of the area, the upper unit appears to be represented by only a 2-foot-thick resistant siltstone bed near the top of the South Platte equivalent.

The following stratigraphic section, measured at the north end of Battle Ridge, shows the lithology of the Dakota Sandstone in the northern part of the area:

Section of the Dakota Sandstone in N½ sec. 8, T. 11 N., R. 81 W.

Benton Shale (Mowry Shale Member):	
Shale, dark-brownish-gray, very light gray, weathering, thin-bedded to laminated; weathers into hard, brittle, flat chips; contains abundant fish scales.	
Dakota Sandstone:	
South Platte equivalent:	*Feet*
Poorly exposed; appears to be all shale; weathers to mottled brown and gray; sticky and plastic when wet; unit probably bentonitic and nonresistant	22
Siltstone, light-brown to greenish-gray, yellowish-gray-weathering-thin-bedded to laminated; many weathered bedding surfaces are curved; contains fairly abundant fish scales; very hard, ledge forming	2
Poorly exposed to covered; appears to be all nonresistant shale that weathers dark bluish gray and dark brownish gray; unit becomes browner upward	57
Poorly exposed to covered; appears to be mostly yellowish-gray sandstone that weathers to mottled rusty brown and is very fine grained; contains a 3-ft resistant sandstone bed near middle	10
Offset along the strike about 1,000 ft to the north	
Sandstone, very light gray (a few yellow streaks near base), very fine grained, even bedded; weathers into slabs 3 to 12 in. thick; resistant; makes hogback and dip slope	15
Poorly exposed; mostly sandstone; lower part is grayish brown; upper part, medium to light gray; unit is very fine grained, becoming medium grained near top	16
Siltstone, light-green to brownish-gray, clayey; weathers to small blocky chips; unit contains some very thin lenses of gray to black shale	5
Total South Platte equivalent	127

Dakota Sandstone—Continued	
Lytle equivalent:	*Feet*
Claystone, mottled yellowish-gray to pink (at base), gray (near top), light-yellow-weathering, silty	7
Siltstone, brick-red, ferruginous cemented, hard, ledge forming	1
Poorly exposed; appears to be all orange-brown to reddish-brown fine-grained sandstone	5
Poorly exposed; mostly sandstone that is light rusty brown and very fine grained	2
Sandstone, light-yellowish- to grayish-brown, medium-grained; contains grains of soft white to pale-yellow clay mineral; some iron staining along bedding planes; crossbedded; contains very sparse scattered pebbles of chert and quartzite	5
Sandstone, light-brown, rusty-brown-weathering, medium-grained, crossbedded, friable, nonresistant	4
Poorly exposed; mostly light-brown sandstone having at least one dark-red streak; unit is very fine grained; massive	8
Conglomerate, yellowish- to grayish-brown; weathers light rusty brown; sandstone matrix is medium to coarse grained; contains abundant grains and cement of soft white clay mineral. Pebbles occur irregularly, both in lenses and disseminated, and consist mostly of subrounded chert and quartzite, ranging from about 1/16 to 3/4 in. in length; also present are a few crinkly layers of ferruginous sandstone and siltstone; unit is crossbedded; weathers into rounded ledges; resistant, forms hogback; base covered by pebble float; contact with Morrison Formation taken at break in slope	30
Total Lytle equivalent	62
Total Dakota Sandstone	189
Morrison Formation:	
Covered.	

The following composite stratigraphic section, measured on the prominent hill between Sheep Mountain and Delaney Butte, shows the lithology of the Dakota Sandstone in the south-central part of the area:

Composite section of the Dakota Sandstone in E½ sec. 27, T. 9 N., R. 81 W.

Benton Shale (Mowry Shale Member):	
Shale, medium- to dark-gray, light to very light gray weathering, commonly mottled, thin bedded to laminated; contains sparse fish-scale imprints; weathers platy.	
Dakota Sandstone:	
South Platte equivalent:	*Feet*
Poorly exposed; mostly sandstone probably interbedded with shale; sandstone is light brownish gray, weathers light brown, contains fairly abundant fragments and films of carbonaceous material, is very fine grained to silty, thin bedded, and obscurely cross-laminated, and weathers into slabs 1–8 in. thick; some bedding surfaces contain markings that are possibly worm-burrow casts; unit contains sparse fish-scale imprints; entire unit resistant, makes conspicuous dip slope	28

Dakota Sandstone—Continued

South Platte equivalent—Continued	Feet
Poorly exposed, nonresistant unit; mostly shale and thin beds of siltstone. Shale is dark gray to black, silty, and thin bedded to laminated; contains abundant carbonaceous material along bedding planes. Siltstone is mottled gray to dark gray, has abundant carbonaceous material occurring both disseminated and on bedding planes, is obscurely even bedded and cross-laminated. Some weathered bedding surfaces contain markings that are possibly worm-burrow casts	21
Sandstone, brownish-gray to light-gray (lower part weathers rusty brown, upper part weathers mottled purple to brownish gray), fine grained to very fine grained; contains sparse to abundant carbonaceous material; bedding in lower part is obscure; upper part is even bedded and cross-laminated and weathers to rectangular blocks; some weathered surfaces ripple marked and contain markings that are possibly worm-burrow casts; entire unit only moderately resistant	19
Poorly exposed, nonresistant unit; mostly shale and thin beds of sandstone. Shale is light grayish green, has sparse brown and dark-gray mottling, and is silty to sandy. Sandstone is light brownish gray, very fine to fine grained, slightly calcareous, contains black carbonaceous material on bedding planes; even-bedded; weather to slabs ¼ to 1 in. thick	14
Total South Platte equivalent	82
Lytle equivalent:	
Sandstone containing lenses of conglomeratic sandstone. Sandstone is light brownish gray, weathers rusty brown owing to limonite-stained clay cement, contains some light-gray beds in middle and upper part of unit, and is mostly fine to very fine grained but contains a few medium-grained beds; pebbles are chert and quartzite, occurring mostly in thin lenses in the light-gray sandstone beds; entire unit is obscurely crossbedded, and weathers to slabs ¼ to 1 in. thick	27
Sandstone, mostly rusty-brown; some very light gray beds. Rusty-brown sandstone is medium grained, cemented by limonite-stained clay, and contains very sparse scattered chert and quartz pebbles. Light-gray sandstone is very fine grained, has abundant coarse grains, contains some calcareous siltstone. Entire unit resistant and ledge forming	3
Sandstone, light-grayish-brown (light-brownish-gray clay cement), fine- to medium-grained, contains very sparse chert and quartzite pebbles; obscurely crossbedded, moderately resistant	10
Covered, nonresistant	8
Sandstone, light-yellowish-brown (contains light-brownish-yellow clay grains and cement), medium- to coarse-grained, contains sparse chert grains and a few lenses and stringers of conglomeratic sandstone; obscurely crossbedded, nonresistant	7

Dakota Sandstone—Continued

Lytle equivalent—Continued

	Feet
Conglomeratic sandstone, light-yellowish-brown. Sandstone is medium grained, contains abundant light-yellow clay grains and cement, and sparse chert grains, and is friable. Pebbles are chert and quartzite as much as 1 in., but mostly ½ in. long, which occur irregularly both in lenses and disseminated. Unit is crossbedded and moderately resistant, weathers to thick irregular blocks and slabs. Base not exposed. Contact with Morrison Formation taken at obscure break in slope	34
Total Lytle equivalent	89
Total Dakota Sandstone	171

Morrison Formation:

Poorly exposed; mostly claystone, greenish gray, nonresistant.

The following partial stratigraphic section, measured near Norris Creek at the south end of Pitchpine Mountain, shows the lithology of the middle and upper parts of the South Platte equivalent in the southwestern part of the area:

Partial section of the Dakota Sandstone in SW¼ sec. 13, T. 8 N., R. 82 W,

Benton Shale (Mowry Shale Member):

Shale, dark-gray, light-brownish-gray weathering, silty, cross-laminated, hard, brittle; weathers to thin chips; sparse fish scales.

Dakota Sandstone (part):

South Platte equivalent (part):

	Feet
Siltstone, mottled gray and brown, contains abundant carbonaceous material both disseminated and as films on bedding planes; contains some very fine grained sand; evenbedded, cross-laminated; weathers to small rectangular blocks; very hard; forms conspicuous dip slope	2
Shale and sandstone interbedded; unit consists mostly of black shale, weathers dark gray; sandstone is light gray, very fine grained to silty, thin bedded, and cross-laminated; some weathered bedding surfaces contain markings that are possibly worm-burrow casts; entire unit contains thin sparse streaks of yellow bentonite	8
Sandstone, mottled gray and brown, very fine grained; contains abundant clay and carbonaceous material; irregularly thin, evenbedded, cross-laminated, mostly nonresistant	2
Sandstone, mottled brown and gray, light-gray weathering, very fine grained, contains abundant black carbonaceous material mostly along bedding surfaces; contains abundant chert grains; obscurely evenbedded, cross-laminated, resistant, ledge forming; some weathered bedding surfaces contain markings that are possibly worm-burrow casts	5

Dakota Sandstone (part)—Continued

South Platte equivalent—Continued

	Feet
Poorly exposed; mostly shale containing a few thin beds of sandstone and streaks of bentonite. Shale is black and weathers to dark gray small fragments. Sandstone is light gray, weathers light yellowish-gray; very fine grained to silty; abundant carbonaceous material occurs as films along bedding planes and also is disseminated, obscurely evenbedded; cross-laminated; weathers to slabs having curved surfaces; weathered surfaces contain abundant markings that are possibly worm-burrow casts	15
Sandstone, light-gray, light-brown weathering, fine- to medium-grained, contains sparse chert grains, evenbedded, weathered bedding surfaces conspicuously ripple marked; also contains some mud cracks and markings that are possibly worm-burrow casts; resistant, forms conspicuous dip slope	5
Partial thickness, South Platte equivalent	37

Covered.

The following partial stratigraphic section, measured near Raspberry Creek about 1¼ miles west of Pitchpine Mountain, shows the lithology of the Lytle equivalent in the southwestern part of the area:

Partial section of the Dakota Sandstone in NW¼ sec. 14, T. 8 N., R. 82 W.

Dakota Sandstone (part):

South Platte equivalent (part):

	Feet
Sandstone, light-brown, rusty-brown-weathering, fine- to medium-grained; contains sparse pods of carbonaceous material; lower part contains sparse stringers of chert- and quartzite-pebble conglomerate; massive to even bedded, cross-laminated, hard; weathers to crudely rectangular slabs having irregular or ripple-marked bedding surfaces; forms resistant ridge and dip slope from which higher beds have been eroded	33

Lytle equivalent:

	Feet
Poorly exposed, top and base covered; includes siltstone and claystone. Siltstone is yellowish gray, obscurely thin bedded, cross-laminated, and calcareous; weathers into slabs ¼ to 1 in. thick. Claystone is dark red and grayish green. Entire unit nonresistant	14
Sandstone, light-brownish-gray, fine- to medium-grained; contains thin lenses and stringers of chert- and quartzite-pebble conglomerate and sparse scattered pebbles; contains abundant grains of soft white clay mineral; massive, obscurely crossbedded, resistant, ledge forming	17
Conglomerate, light-brownish-gray; sandstone matrix is fine to medium grained; pebbles are subrounded chert and quartzite as much as about 1 in. in length (most are about ¾ in. long); base of unit contains grayish-green claystone fragments as much as 6 in. long	3
Sandstone, light-brown, medium-grained; contains sparse scattered chert and quartzite pebbles and abundant grains of soft white clay mineral; obscurely crossbedded	5

Dakota Sandstone (part)—Continued	
South Platte equivalent—Continued	*Feet*
Conglomerate, light-gray light-brown-weathering; sandstone matrix is medium grained; pebbles are subrounded chert and quartzite, mostly ¼ to ½ in. long, largest as much as 1½ in.; pebbles occur in lenses and stringers and disseminated through sandstone matrix; fairly resistant, ledge forming; base of unit taken at break in slope	48
Total Lytle equivalent	87
Morrison Formation:	
Covered.	

Correlation.—The Dakota Sandstone in northwestern North Park has about the same lithology and stratigraphic position as it does along the east side of the northern Front Range as redefined by Lee (1927, p. 17–23) and by Waagé (1955, p. 46). In the northern Front Range the contact between the Morrison Formation and the overlying Dakota Sandstone is sharp and probably unconformable. The contact of the Dakota Sandstone with the overlying Benton Shale, although gradational, is easily distinguished in both areas.

In the Laramie Basin of Wyoming, rocks correlative with the Dakota Sandstone of northwestern North Park include the Cloverly Formation, the Thermopolis Shale, the Muddy Sandstone, and that part of the Mowry Shale below platy siliceous shale beds where such beds are included in the Mowry.

In northwestern Colorado, rocks correlative with the Dakota Sandstone of northwestern North Park are generally designated Dakota Sandstone (Cobban and Reeside, 1952, chart 10B), although the name has not been consistently used to include the lower conglomeratic beds equivalent to the Lytle Formation.

No fossils were found in the Dakota of northwestern North Park other than carbonized plant fragments and fish scales in the South Platte equivalent. Waagé (1955, p. 27) considered the Lytle Formation to be Early Cretaceous on the basis of physical correlation with sparsely fossiliferous beds in Wyoming. Beds equivalent to the dark shale unit of the South Platte Formation contain a marine invertebrate fauna of Early Cretaceous age at various localities along the northern Front Range of Colorado and adjacent areas of Wyoming. Reeside (1923, p. 199–201) described several collections of marine invertebrates from this area and identified, among others, *Inoceramus comancheanus* Cragin. *I. comancheanus* is considered an Early Cretaceous zonal index fossil by Cobban and Reeside (1952, chart 10B). Inasmuch as the South Platte Formation underlies the Mowry Shale which contains Early Cretaceous ammonites (Cobban and Reeside, 1951, p. 1892), the upper beds of the South Platte must also be Early Cretaceous in age.

LOWER AND UPPER CRETACEOUS SERIES

BENTON SHALE

Definition.—Meek and Hayden (1862, p. 419, 420–422) applied the name Fort Benton Group to strata overlying their Dakota Group and underlying their Niobrara Division. The name was taken from Fort Benton in northwestern Montana. More recently, the name Benton Shale has been commonly used.

This report follows the terminology as applied by Steven (1954; 1960, p. 346–348) in the Northgate district of North Park. The name Benton Shale is applied to the marine beds conformably overlying the Dakota Sandstone and underlying, with possible unconformity, the Niobrara Formation. The Benton Shale is divided into three members. These are in ascending order: the Mowry Shale Member, the middle shaly member, and the Codell Sandstone Member. These members are not differentiated on the geologic maps (pls. 1–3). Beekly (1915, p. 34–39) originally used the name Benton Shale in North Park, applying the name to the beds between the Dakota Sandstone and the Niobrara Formation. However, he apparently mapped the base of the Benton at the top of the most resistant hogback-forming sandstone bed of the Dakota, which is not the same bed at all places in North Park. Nevertheless, he (1915, p. 37) correlated the basal beds of the Benton in North Park with the Mowry Shale of the Laramie, Wyo., area on the basis of like lithology.

Thickness.—The Benton Shale ranges in thickness from about 500 to about 650 feet. Apparently it is thinnest in the Carter Oil Co. Government-McDannald 1 test hole in sec. 4, T. 10 N., R. 80 W., in the northeastern part of the area. It is thickest in secs. 32 and 33, T. 11 N., R. 81 W. The Mowry Shale Member ranges from about 95 to about 135 feet in thickness and apparently thins toward the south. The middle shaly member varies considerably in thickness and ranges from about 340 feet in the Carter Co. test hole to about 480 feet in the outcrop area about 1 mile east of the Hill Ranch in sec. 32, T. 11 N., R. 81 W. The top of the formation is commonly covered, and complete exposures of the Codell Sandstone Member are sparse; the Codell appears to range in thickness from about 35 to 65 feet.

Distribution and topographic expression.—The Benton Shale crops out almost continuously in a band on the east side of the Delaney Butte–Sheep Mountain highland from the south end of Delaney Butte to the north end of Battle Ridge, except for some local areas covered by Quaternary surficial deposits. The formation also crops out in a fairly extensive area east and west of Pitchpine Mountain in the southwestern part of the area. Small discontinuous outcrops are found along the flank of the Park Range as far north as Monahan Creek, but through most of this area the Benton is covered by terrace gravels or glacial drift. The Benton crops out in a small area northwest of Sheep Mountain near the Boettcher Ranch and is probably present beneath colluvium on the west slope of Sheep Mountain and the east slope of Delaney Butte. The Mowry Shale Member crops out in the valley of Parsons Draw on the north side of Independence Mountain.

The Mowry Shale Member, at the base of the formation, is topographically dominated by the immediately underlying resistant hogback-forming sandstone beds of the Dakota Sandstone. It generally forms a low ridge at the foot of the Dakota dip slope. The Mowry characteristically weathers into a rubble of small, platy, brittle chips (fig. 5) which in many places cover the unit and stratigraphically higher beds downslope. The middle shaly member, which makes up roughly two-thirds of the Benton, is soft and nonresistant and forms valleys and flatlands masked at most places by surface wash and soil. Lake John occupies a basin centered in the soft, easily eroded beds of the Benton, and which was probably deflated by wind. The Codell Sandstone Member at the top of the formation is resistant relative to the enclosing shaly beds and forms a low but persistent ridge throughout its outcrop area.

Lithology.—The Mowry Shale Member consists of 95 to 135 feet of interbedded marine shale, siltstone, and bentonitic shale. The shale

FIGURE 5.—Weathered slope on outcrop of the Mowry Shale Member of the Benton Shale, showing typical light-gray-weathering platy brittle chips of the shale at the north end of Battle Ridge in the SE¼ sec. 8, T. 11 N., R. 81 W.

predominates and is hard, brittle, and fissile to platy. The siltstone beds are gradational in lithology with the shale beds, and differ mainly in the content of silt-sized detrital quartz. Fresh surfaces are usually distinctive dark shades of gray and brown. Fish scales and bone fragments are abundant in many of the shale and siltstone beds. The bentonitic shale beds are thin and inconspicuous in most outcrops owing to cover by fragments of shale and siltstone. At the south end of Pitchpine Mountain, the Mowry Shale Member contains eight beds of bentonitic shale ranging from ½ to 4 feet in thickness. The base of the Mowry Shale Member is conformable upon the underlying South Platte equivalent of the Dakota Sandstone, and the lithologies of the two units interfinger within a narrow transition zone. From Delaney Butte southward, siltstone predominates in the transitional zone, and the contact is placed at the top of the most resistant siltstone bed. Rocks below this contact generally contain increasing amounts of carbonaceous material. Northward from Delaney Butte, the transitional zone becomes predominantly shaly, and the contact is placed at the base of the lowest hard platy shale beds.

The lower part of the middle shaly member of the Benton Shale consists predominantly of dark noncalcareous marine shale that contains minor interbedded bentonite and sparse but conspicuous bluish-gray clay-ironstone concretions. The shale is soft, fissile, and conspicuously very dark gray to almost black, both on weathered and fresh surfaces. The dark weathering contrasts with the predominantly light-gray weathering of the underlying Mowry Shale Member and with the brown weathering of overlying limestone and calcareous shale beds. Bentonite beds occur throughout the lower part of the middle shaly member. They are mostly thin, but a bed 7 feet thick crops out about 90 feet above the base of the member near the north end of Battle Ridge. Very hard bluish-gray clay-ironstone concretions are characteristic of the lower part of the member. They are seldom seen intact; but fragments of them are abundant and, in many areas of poor exposures, are the chief means of identifying the member.

Near the middle of the middle shaly member are beds which may be equivalant to the Greenhorn Limestone of eastern Colorado. These beds are exposed only at the locality of the measured section at the south end of Lake John. They are only 5½ feet thick and consist of two thin beds of clastic marine limestone separated by a bed of calcareous shale. The limestone is thin bedded, fine grained, and light brown; freshly broken pieces have a strong petroleum odor. Although the limestone beds are resistant, they are too thin to form conspicuous ledges.

The upper part of the middle shaly member is nowhere well enough exposed to be seen in detail. It appears to be mostly nonresistant calcareous platy dark-gray brown-weathering marine shale. Locally, the upper part contains limestone, as indicated by fragments found about one mile east of the Hill Ranch in the northern part of the area.

The Codell Sandstone Member of the Benton Shale consists of even-bedded brown limestone, nonresistant even-bedded calcareous sandstone, and dark calcareous shale (fig. 6). The limestone is composed

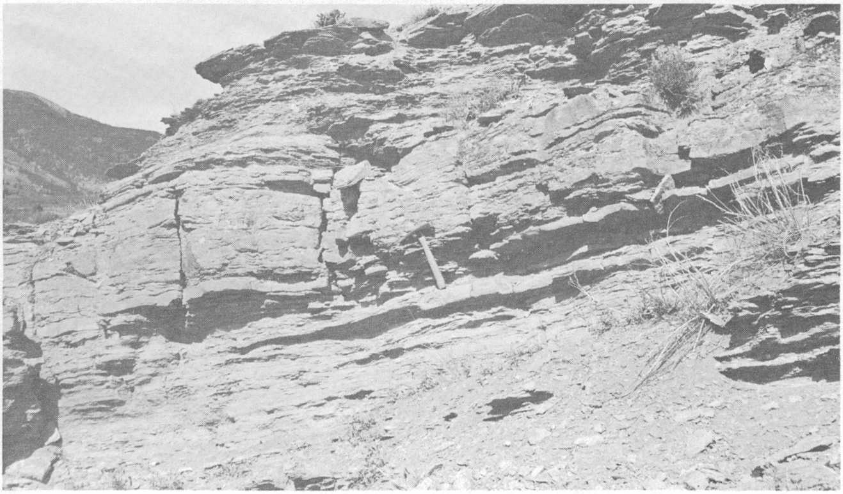

FIGURE 6.—Resistant sandstone and limestone beds at the top of the Codell Sandstone Member; exposed on the north bank of Roaring Fork in the SW¼ sec. 6 and the NW¼ sec. 7, T. 8 N., R 81 W.

mainly of detrital calcite, and many beds are a coquinalike mass of broken fossil shells. Most freshly broken pieces of the limestone have a strong petroleum odor. The limestone beds are resistant and throughout the area a particularly useful stratigraphic marker. Quartz sand is a conspicuous constituent of the Codell Sandstone Member near the south end of Lake John and apparently increases in amount southward; at the locality of the measured section along Hell Creek in the southwestern part of the area, calcareous sandstone beds compose much of the upper part of the unit.

The following stratigraphic section of the Benton was measured at the south end of Lake John in the central part of the area:

Section of Benton Shale in SE¼ sec. 10 and SW¼ sec. 11, T. 9 N., R. 81 W.

[Fossils identified by W. A. Cobban]

Niobrara Formation (Fort Hays Limestone Member):

Limestone, clastic, light-brownish-gray, even-bedded, nonresistant; composed mainly of very fine grained detrital calcite; also contains abundant silt- and sand-sized grains of quartz and fragments of other minerals and rocks, including some biotite and a soft green mineral.

745-100 O—65——4

	Feet
Benton Shale:	
Codell Sandstone Member:	
Poorly exposed; interbedded clastic sandy limestone and silty calcareous light-brownish-gray shale; unit is thin bedded, moderately resistant, and ledge forming	25
Limestone and minor interbedded shale. Limestone is medium brown; weathers light brown; is mostly fine-grained detrital calcite containing some coarsely crystalline beds and very minor detrital quartz; is hard, even bedded, and cross-laminated; weathers in rough-surfaced slabs ½ to 4 in. thick; has strong petroleum odor from freshly broken surfaces; and has abundant fossil shells, mostly broken. Shale is dark gray, weathers grayish brown, and is silty, and calcareous. Entire unit resistant and ledge forming. (USGS Mesozoic loc. D1114. *Inoceramus dimidius* White, *Prionocyclus wyomingensis* Meek)	15
Poorly exposed; mostly gray calcareous shale and brownish-gray thin-bedded calcareous nonresistant siltstone	17
Limestone, clastic, grayish-brown, light-brown weathering fine-grained, thin, even-bedded, cross-laminated; weathers along curved, irregular, possibly ripple-marked bedding surfaces; has strong petroleum odor from freshly broken surfaces; contains abundant fossil shells, mostly broken; resistant, ledge-forming	6
Total Codell Sandstone Member	63
Middle shaly member:	
Poorly exposed, nonresistant; mostly dark-gray to black calcareous platy shale; weathers dark grayish brown to yellowish brown	130
Shale, dark-gray, calcareous, silty, platy to fissile	3
Limestone, clastic, light-brown, dark-brown weathering, fine-grained, thin-bedded, has strong petroleum odor from freshly broken surfaces; hard, resistant, ledge forming	2
Shale, dark-gray, calcareous, silty, platy to fissile	3
Limestone, clastic, light-brown, dark-brown weathering; fine-grained, thin-bedded; strong petroleum odor from freshly broken surfaces; resistant, ledge forming	½
Shale, dark-gray, calcareous	5
Covered to poorly exposed; mostly nonresistant dark-gray to black shale; weathers dark gray; is mainly noncalcareous, becoming calcareous in upper part	112
Poorly exposed; mostly dark-bluish-gray to bluish-black noncalcareous very soft nonresistant shale; better exposures in lower part of unit contain a few thin beds of yellow bentonite and scattered fragments of dark-bluish-gray clay-ironstone concretions	120
Poorly exposed; mostly dark-gray to black noncalcareous shale; float contains bluish-gray to grayish-purple fragments of clay-ironstone concretions	32
Total middle shaly member	407½

Benton Shale—Continued	
Middle shaly member and Mowry Shale Member:	*feet*
Covered, nonresistant; sparse surface float is fissile silty shale containing abundant fish scales. Contact of middle shaly member and Mowry Shale Member is in this interval	63
Mowry Shale Member:	
Covered	54
Poorly exposed; mostly dark-gray shale; weathers very light gray; is silty to nonsilty, brittle, and platy to fissile; contains abundant fish scales; base covered; contact with Dakota Sandstone obscure	±30
Total Mowry Shale Member	±84
Total Benton Shale (rounded)	±620
Dakota Sandstone:	
Covered.	

The following partial stratigraphic section, measured on the north bank of Roaring Fork, shows the lithology of the upper part of the Codell Sandstone Member in the southwestern part of the area:

Partial section of the Benton Shale in SW¼ sec. 6 and NW¼ sec. 7, T. 8 N., R. 81 W.

Niobrara Formation (Fort Hays Limestone Member):
Limestone, clastic, light-brownish-gray, light-yellowish-gray weathering; composed of silt-sized calcite fragments, considerably recrystallized; weathers to fissile and platy rough-surfaced chips; relatively nonresistant.

Benton Shale:	
Codell Sandstone Member:	*Feet*
Limestone, clastic, dark-grayish-brown, light-brown, weathering, composed of fine-grained detrital calcite, considerably recrystallized; contains sparse detrital quartz grains; thin, even bedded; weathers mostly to irregularly surfaced slabs about 1 to 10 in. thick; has some fissile parts; has strong petroleum odor from freshly broken surfaces; very hard, forms prominent ledge and dip slope; and contains abundant fossil shells, mostly broken	5
Sandstone, brownish-gray, yellowish-brown weathering, fine-grained, calcareous; contains abundant dark grains; thin bedded, cross-laminated; many bedding surfaces contain films of black carbonaceous material; friable, relatively nonresistant; contains a few thin beds of clastic limestone	9
Limestone, clastic, dark-grayish-brown, light-brown weathering; composed of fine-grained detrital calcite, considerably recrystallized; contains sparse detrital quartz grains; even bedded; joints are calcite coated; has strong petroleum odor from freshly broken surfaces; contains sparse broken fossil shells; very hard, ledge forming	3

Benton Shale—Continued	
Codell Sandstone Member—Continued	*Feet*
Sandstone, grayish-brown, light-brown weathering, fine-grained, calcareous; contains abundant dark grains; some bedding surfaces contain films of black carbonaceous material; thin bedded, cross-laminated; weathers to curved and uneven slabs; relatively nonresistant	7
Covered, probably nonresistant shale	30
Partial thickness, Benton Shale	54
Valley alluvium.	

The following stratigraphic section, measured on the north bank of Norris Creek at the south end of Pitchpine Mountain, shows the lithology of the Mowry Shale Member of the Benton Shale in the southwestern part of the area:

Partial section of the Mowry Shale Member of the Benton Shale in SW¼ sec. 13, T. 8 N., R. 82 W.

Benton Shale (part):	
Mowry Shale Member (part):	*Feet*
Covered; float from uppermost part is soft black fissile shale; top of Mowry Shale Member probably somewhere in this interval	10
Poorly exposed; mostly silty to nonsilty shale and minor amounts of black to dark gray siltstone; weathers medium to bluish gray; contains fish scales; even bedded; weathers to fissile or blocky fragments; mostly nonresistant	14
Siltstone, dark-gray to black, weathers to mottled shades of drab green, purple, and brown, thin-bedded, cross-laminated; weathers to platy or blocky pieces as much as 1 in. thick; has conspicuous fractures along joints at right angles to bedding; very hard; forms dip slope	2
Shale, black, light-bluish-gray weathering, mostly nonresistant; weathers to brittle fissile or blocky chips	11
Shale, dark-gray to black, silty, cross-laminated; weathers to hard brittle fissile to platy pieces; contains fish scales; fairly resistant, ledge forming	16
Bentonitic shale, light-gray yellowish gray weathering, nonresistant	½
Siltstone, black, thin-bedded, cross-laminated; weathers to fissile or platy fragments; very hard	½
Bentonitic shale, light-brownish-yellow, fissile, nonresistant	½
Shale, black; weathers various shades of light gray and brown; weathers to fissile or blocky fragments; hard, brittle	1
Shale, black, medium- to light-gray and brownish-gray weathering; contains fish scales; hard, brittle, weathers to fissile or platy fragments; forms dip slope	18
Bentonitic shale, light-brownish-yellow, fissile, nonresistant	1
Shale, black, bluish- to brownish-gray weathering, hard, brittle; weathers to fissile, platy, or blocky fragments	½
Bentonitic shale, light brownish-yellow, fissile, nonresistant	½

Benton Shale (part)—Continued	
Mowry Shale Member (part)—Continued	*Feet*
Shale, black, bluish- to brownish-gray weathering, hard, brittle; weathers to fissile, platy, or blocky fragments	3
Bentonitic shale, light-brownish-yellow, fissile, nonresistant	1
Shale, black; weathers mottled brownish purple and bluish black, hard, brittle, weathers to platy or blocky fragments; resistant; forms conspicuous dip slope	8
Bentonitic shale, light-yellowish-brown; weathers mottled brown and orange	½
Shale, dark-gray, bluish-gray weathering; contains abundant fish scales; thin-bedded; hard, brittle; weathers to platy or blocky fragments; resistant; forms dip slope	1
Bentonitic shale, light yellowish-brown, brown, and orange; interbedded with thin beds of nonresistant gray clay shale which is mostly fissile, but weathering obscures shaly structure; entire unit nonresistant	4
Siltstone, dark-gray to black, weathers mottled gray and purplish brown; thin bedded; weathers to platy or blocky fragments; very hard, forms dip slope; contains abundant fish bones and scales	3
Shale, dark-gray to black; weathers mottled brownish gray; silty, thin bedded, cross-laminated, hard, brittle; weathers to platy or blocky fragments	2
Siltstone and shale, interbedded, gray to black; weathers mottled light-gray to brown. Siltstone is thin bedded, weathers to platy or blocky fragments, hard, and forms dip slope. Shale is irregularly fissile	1
Bentonitic shale, pale-orange to grayish-yellow; weathering has distorted fissile structure; contains a ½-ft bed of soft gray clay shale; entire unit nonresistant	2
Shale, dark-gray, light-brownish gray weathering; silty, contains sparse fish scales; cross-laminated, hard, brittle; weathers to thin chips	1
Partial thickness, Mowry Shale Member	102
Dakota Sandstone (South Platte equivalent):	
Siltstone, mottled gray and brown; contains abundant carbonaceous material; even-bedded, cross-laminated; weathers to blocky fragments; very hard; forms conspicuous dip slope.	

Correlation.—The Benton Shale of northwestern North Park is equivalent to the Benton Shale of the northern Front Range area in Colorado. In both areas the lower boundary is generally placed at the top of the highest sandstone or siltstone of the Dakota Sandstone or at the base of the platy beds of the Mowry Shale Member or its equivalent; the upper boundary is placed at the top of the Codell Sandstone Member. The uppermost sandy beds of the Benton Shale are commonly designated Codell Sandstone Member of the Carlile Shale, in the Front Range foothills area (Mather, Gilluly, and Lusk, 1928, p. 81).

In the Laramie Basin, Wyo., beds correlative with the Benton Shale of northwestern North Park include the Mowry Shale and the Frontier Formation. The Mowry Shale Member of this report and the Mowry Shale of the Laramie Basin appear to be identical in lithology, however, where nonresistant dark shale beds underlie resistant platy shale in the Laramie Basin, such beds are commonly included with the Mowry.

In northwestern Colorado the lower part of the Mancos Shale includes all the equivalents of the Benton Shale of northwestern North Park.

Identifiable fossils were found only in the Codell Sandstone Member at the top of the formation. Collections from two localities were examined by W. A. Cobban. The first collection was taken from the outcrop at the south end of Lake John in the SW¼ sec. 11, T. 9 N., R. 81 W. (USGS Mesozoic loc. D1114). This collection includes the pelecypod *Inoceramus dimidius* White, and the ammonite *Prionocyclus wyomingensis* Meek. Cobban reported (written commun., 1956): "These fossils are guides to rocks equivalent to the middle part of the Carlile shale." The second collection was taken about 1¼ miles southeast of the Hill Ranch in the SW¼ sec. 33, T. 11 N., R. 81 W. (USGS Mesozoic loc. D1115). This collection contained *Inoceramus dimidius* White, *Prionocyclus wyomingensis* Meek, and also the ammonite *Scaphites warreni* Meek and Hayden. According to Cobban and Reeside (1952, p. 1018, chart 10b) these three forms are also found in the Turner Sandy Member of the Carlile Shale and its equivalents, the Codell Sandstone Member of the Carlile Shale and the Wall Creek Sandstone Member of the Frontier Formation.

Fossils and rocks correlative with the Sage Breaks Member at the top of the Carlile Shale in eastern Wyoming are not present in northwestern North Park, their absence indicating a hiatus between the top of the Codell Sandstone Member and the overlying Fort Hays Limestone Member of the Niobrara Formation.

The top of the Mowry Shale is considered as marking the time boundary between Early and Late Cretaceous (Cobban and Reeside, 1952, chart 10b) in nearby areas, and it is assumed that the top of the Mowry Shale Member of the Benton Shale likewise marks this time boundary in northwestern North Park.

UPPER CRETACEOUS SERIES

NIOBRARA FORMATION

Definition.—The Niobrara Formation is a very widespread marine unit, recognizable throughout the northern Great Plains and much of the eastern Rocky Mountain area. The name Niobrara Division was applied by Meek and Hayden (1862, p. 419, 422–423) to the beds between their Dakota Group and their Fort Pierre Group. The type area is at the mouth of the Niobrara River in northeastern Nebraska. Niobrara Formation rather than Niobrara Division is the name now commonly used throughout the Great Plains and Rocky Mountains, but in general the formation includes the same stratigraphic interval as originally defined by Meek and Hayden.

In northwestern North Park, the Niobrara Formation includes calcareous marine beds overlying, with possible unconformity, the Benton Shale and conformably underlying the Pierre Shale. This usage follows that of Beekly (1915, p. 39–42, and pl. 12) and of Steven (1954), except that the upper boundary of the Niobrara of this report is placed at a somewhat lower stratigraphic horizon than that apparently recognized by Beekly. In this report, the Niobrara is divided into the Fort Hays Limestone Member, at the base, and the Smoky Hill Shale Member, at the top. The Fort Hays Limestone Member is too thin to be differentiated on the geologic map, and therefore the Niobrara is shown as a single unit.

Thickness.—The Niobrara Formation is apparently fairly uniform in thickness throughout the area, ranging only from about 700 to 720 feet in thickness, where not overlapped by the Coalmont Formation. It is about 700 feet thick in the Carter Oil Co. Government-McDannald 1 test hole in sec. 4, T. 10 N., R 80 W., in the northeastern part of the area and in a section measured along the bank of the North Fork of the North Platte River near Lake John in the south-central part of the area and is about 720 feet thick in a section measured on the north bank of Roaring Fork in the southwestern part of the area. The range of thickness of the basal member, the Fort Hays is not well known owing to lack of good exposures. The thickness of the Fort Hays at the locality of the measured section on the north bank of Roaring Fork is 17 feet; it probably does not exceed about 20 feet anywhere in the area.

Distribution and topographic expression.—The Niobrara Formation crops out mainly in a north-trending band in the central part of the area from the Roaring Fork northward to Independence Mountain. It is considerably obscured by Quaternary surficial deposits throughout this extent. The formation crops out in an irregular northeast- and north-trending band in the central part of the Pitchpine Mountain quadrangle in the southwestern part of the area. Here also, surficial deposits obscure much of the outcrop. The Niobrara also crops out irregularly on the west sides of Delaney Butte and Sheep Mountain and may occupy an extensive area beneath the colluvium on the west side of Sheep Mountain.

The Niobrara Formation is mostly nonresistant and commonly forms valleys or flat lowlands. Good exposures are rare except at a few places where the formation is resistant enough to form conspicuous outcrops. Lake John and North and South Delaney Lakes occupy basins probably created by wind deflation in part on the nonresistant shale of the Niobrara. The thin Fort Hays Limestone Member is more resistant than the overlying Smoky Hill Shale Member but is dominated topographically by the resistant, ridge-forming limestone or sandstone of the immediately underlying Codell Sandstone Member of the Benton Shale.

Lithology.—The Fort Hays Limestone Member consists of interbedded marine limestone and dark calcareous shale similar to shale of the lower part of the overlying Smoky Hill Shale Member. The limestone is obscurely even-bedded in sharp contrast to the thin, more regular even bedding of the immediately underlying beds of the Codell Sandstone Member of the Benton Shale (fig. 7). Individual limestone beds are lenticular and range in maximum thickness from a few inches to as much as 8 feet. The limestone is composed of detrital calcite, much of which is recrystallized, and minor amounts of quartz and other minerals. Fresh surfaces of the limestone are usually gray to brownish gray; but weathered surfaces characteristically are light

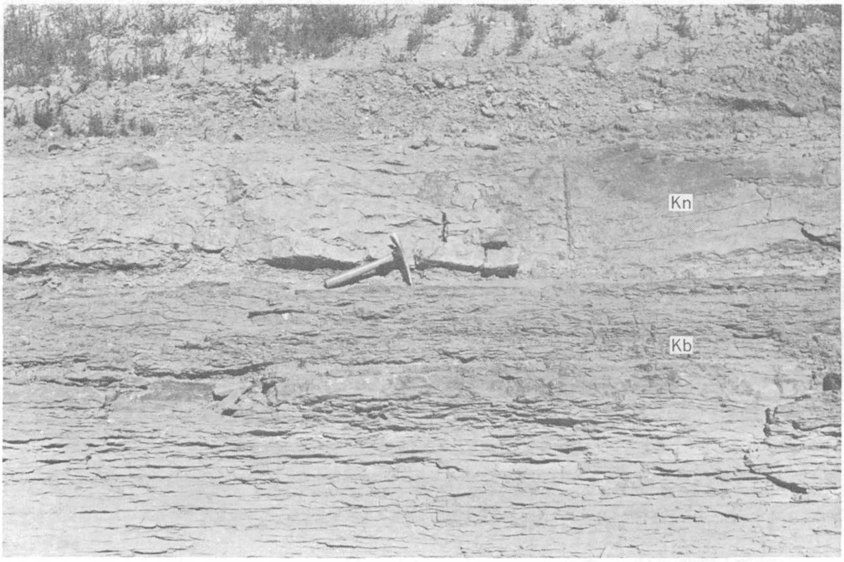

FIGURE 7.—Contact of the Fort Hays Limestone Member of the Niobrara Formation (Kn) with the Codell Sandstone Member at the top of the Benton Shale (Kb). Exposure is in a ditch at the south end of Lake John in the SW¼ sec. 11, T. 9 N., R. 81 W. Hammer point rests on sharp contact between obscurely even bedded Fort Hays above and conspicuously even bedded Codell below; gravelly surficial material on top.

shades of gray and brown, contrasting conspicuously with darker rocks above and below. The basal contact with the underlying Codell Sandstone Member of the Benton Shale is believed to be unconformable, although evidence of unconformity is not conclusive within the area. Where the contact is well exposed, it is sharp (fig. 7), and there is no indication of gradation or interfingering of the Codell and Fort Hays.

Poor exposures throughout the area prevent examining the Smoky Hill Shale Member in much detail, but it consists primarily of calcareous marine shale that contains some thin chalklike limestone beds. It conformably overlies the Fort Hays Limestone Member and the contact is placed at the top of the highest resistant limestone bed of the Fort Hays. The Smoky Hill conformably underlies the Pierre Shale. The shale of most of the member is calcareous enough locally to be termed shaly limestone.

The Smoky Hill Shale Member may be divided roughly into two parts. The lower part is dark nonresistant calcareous shale that generally weathers to drab shades of brown and gray, although lighter colors caused by weathering are present locally. Bedding, although inconspicuous, is generally thin to laminated. White "specks" which probably represent the calcareous shells of marine micro-organisms are present in the lower part but are not nearly so abundant as in higher beds. Fossil shells are fairly abundant but are seldom found intact owning to the nonresistant and thin-bedded character of the enclosing rocks. Hard fragments of *Inoceramus*, however, commonly litter weathered slopes, and in areas of poor exposure, are the only means of identifying the enclosing beds. In general, the lower part of the Smoky Hill is less calcareous than the upper part and the relative amount of lime is the major lithologic difference between the lower and upper parts.

The upper part of the Smoky Hill Shale Member consists of even thin-bedded to very thin bedded light-gray to brown mainly nonresistant highly calcareous shale that characteristically weathers light gray, brown, and yellow. Calcareous white "specks" are very abundant, and hard fragments of fossil *Inoceramus* are common. The upper part of the Smoky Hill Shale Member contains several chalklike limestone beds that are rather soft but are more resistant than the enclosing shale beds and generally form minor ridges. These beds weather a conspicuous very light yellow. Masses of cemented fossil *Ostrea* shells are abundant locally. The top of the uppermost resistant limestone bed is taken as the Niobrara-Pierre boundary.

The boundary between the upper and lower parts of the Smoky Hill is not at the same stratigraphic horizon everywhere in the area. The subdivision into a lower and an upper part is merely a recognition of a gross difference in lithology reflecting the relative content of lime in the Smoky Hill. The more calcareous upper part apparently thickens from north to south at the expense of the less calcareous lower part. Along the bank of the North Fork of the North Platte River near Lake John, the lower part is about 340 feet thick, and the upper part is about 370 feet thick. Along Roaring Fork in the southwestern part of the area, the lower part is about 170 feet thick and the upper part is about 520 feet thick. In general, yellow or yellowish-brown weathering is predominant in the Smoky Hill Shale Member in the northern part of the area, whereas light-gray weathering predominates in the southern part of the area.

The following stratigraphic section, measured along the north bank of Roaring Fork, shows the lithology of the Niobrara Formation in the southeastern part of the area:

Section of the Niobrara Formation

[Upper 685 ft measured in NW¼ sec. 7, T. 8 N., R. 81 W.; lower 17 ft measured in SW¼ sec. 6, T. 8 N., R. 81 W.]

	Feet
Pierre Shale (shaly member):	
Poorly exposed; mostly shale and a few very thin beds of calcareous siltstone and nonresistant silty shale; shale is mainly noncalcareous but becomes calcareous in lower part.	
Niobrara Formation:	
Smoky Hill Shale Member:	
Limestone, grayish-brown, yellowish-brown weathering, speckled, thin-bedded, brittle; weathers to platy or irregular fragments; moderately resistant, ledge forming	8
Shale, drak-gray to dark-brownish-gray, light-gray weathering, calcareous, speckled; weathers to platy fragments; hard, brittle; contains numerous fragments of *Inoceramus*	187
Limestone, grayish-brown, brownish-yellow weathering, speckled; contains abundant layers of crystalline calcite; thin bedded; brittle; weathers to platy or irregular fragments; resistant, ledge forming	12
Poorly exposed; mostly dark-gray to dark-brownish-gray shale; unit is calcareous, speckled, hard, and brittle and weathers light gray; weathers to platy fragments; locally contains some thin-bedded limestone; contains numerous fragments of *Inoceramus;* surface float contains sparse *Ostrea*	308
Shale, dark-gray, light-gray to light-brownish-gray weathering, calcareous; weathers to thin irregular-surfaced chips; mostly nonresistant; *Inoceramus* fragments in surface float. (The stratigraphic horizon about 50 ft above the base of this unit is the same as that at USGS Mesozoic locality D1781 which is 0.4 mile to the northwest and contains *Inoceramus latus* Sowerby and *Baculites cf. B. mariasensis* Cobban.)	170
Thickness, Smoky Hill Shale Member	685

	Feet
Niobrara Formation—Continued	
Fort Hays Limestone Member:	
Limestone, clastic, dark- to medium-gray, light-yellowish-gray weathering; composed of very fine to silt-sized calcite grains, considerably recrystallized; thin, even bedded; weathers to irregular-surfaced slabs, has some fissible parts; resistant forms dip slope	4
Shale, yellowish-gray, slightly calcareous, micaceous; contains sparse sand grains; nonresistant	1
Limestone, clastic, medium-gray; light-yellowish-gray weathering; composed of very fine to silt-sized calcite grains, considerably recrystallized; contains abundant grains of a soft green mineral; even bedded; weathers to blocky fragments; resistant, ledge forming	1
Shale, medium-gray, light-gray weathering, calcareous, nonresistant	1
Limestone, clastic, medium-gray; light-yellowish-gray weathering; composed of silt-sized calcite grains; thin bedded; weathers to blocky or fissile fragments; resistant, ledge forming	2
Limestone, clastic, dark brownish-gray; weathers brownish gray in lower part and yellowish gray upward; composed of silt-sized calcite grains, considerably recrystallized; thin bedded; weathers to thin irregularly surfaced or fissile chips; nonresistant	8
Thickness, Fort Hays Limestone Member	17
Total thickness, Niobrara Formation	702
Benton Shale (Codell Sandstone Member):	
Limestone, clastic, dark-grayish-brown, light-brown weathering; composed of fine-grained calcite, considerably recrystallized; thin, even bedded; weathers mostly to irregularly surfaced slabs about 1 to 10 in. thick; some fissile parts; has strong petroleum odor from freshly broken surfaces; resistant, forms prominent ledge and dip slope; contains abundant fossil shells, mostly broken.	

Correlation.—The Niobrara Formation of northeastern Colorado commonly has been divided in ascending order into either the Timpas and Apishapa Members or the Fort Hays and Smoky Hill Members. The Timpas includes a larger stratigraphic range in the lower part of the Niobrara than the Fort Hays. The Fort Hays-Smoky Hill boundary is more easily recognized than the Timpas-Apishapa boundary in northeastern Colorado, and the Fort Hays and Smoky Hill subdivision of the Niobrara is now more commonly used (Van Horn, 1957; Scott, 1961). The Fort Hays Limestone Member in the Golden, Colo., area as described by Van Horn (1957) is comparable in lithology and thickness with that of northwestern North Park. Van Horn (1957) called the overlying beds of the Niobrara the Smoky Hill Shale Member—a name which is more appropriate for the shaly lithology near the Front Range than is the name Smoky Hill Marl Member which is commonly used in eastern Colorado. The name Smoky Hill Shale Member is used in this report for northwestern North Park.

In the Laramie Basin, Wyo., the Niobrara has been variously subdivided; but current usage places the formation within essentially the same stratigraphic limits as used in this report for northwestern North Park.

In northwestern Colorado lithologic equivalents of the Niobrara Formation lie entirely within the upper part of the Mancos Shale.

Few whole fossils were found in the Niobrara Formation in northwestern North Park, mainly owing to the soft easily eroded nature of the enclosing shale beds, but fragments, principally of *Inoceramus*, are abundant, particularly in the lower part of the Smoky Hill Shale Member. A fossil collection taken on the north bank of Roaring Fork in the SE¼ sec. 1, T. 8 N, R. 82 W. (USGS Mesozoic loc. D1781) about 50 feet above the base of the Smoky Hill Shale Member was examined by W. A. Cobban, who identified the pelecypod *Inoceramus latus* Sowerby, and the cephalopod *Baculites* cf. *B. mariasensis* Cobban. Cobban stated (written commun., 1958): "This is a very early Niobrara fauna. The pelecypod has been found in the lower 6 feet of the Fort Hays limestone in the Front Range area." The upper 3 to 4 feet of the Fort Hays Limestone Member yielded a collection of poorly preserved pelecypods from an outcrop in the SE¼ sec. 1, T. 8 N., R. 82 W. (USGS Mesozoic loc. D2640), about 1,000 feet southwest of locality D1781. The pelecypods were identified by Cobban as *Inoceramus* cf. *I. latus* Sowerby. The characteristic Fort Hays fossil *Inoceramus deformis* was not found. The uppermost limestone bed of the Smoky Hill yielded a small fossil collection in the SW¼ sec. 33, T. 11 N., R. 81 W. This collection, examined by W. A. Cobbin, included *Ostrea congesta* Conrad which, according to Cobban and Reeside (1952, p. 1018–1019) ranges from the Fort Hays Limestone Member to the uppermost part of the Smoky Hill Shale Member. *Ostrea* is found throughout Smoky Hill Shale Member in northwestern North Park and is fairly abundant in the upper limestone beds.

PIERRE SHALE

Definition.—Fort Pierre Group was the name applied by Meek and Hayden (1862, p. 419, 424–427) to the strata between their Niobrara Division and their Fox Hills Beds in the northern Great Plains area. The group was named for old Fort Pierre in present South Dakota. The name Pierre Shale, rather than Fort Pierre Group, has been used since about 1903 and has been applied throughout a very wide area of the northern Great Plains including the Dakotas, Nebraska, Kansas, eastern Wyoming, and eastern Colorado. Throughout this area the Pierre consists predominantly of dark marine shale. Eastward thinning tongues of marine sandstone are present in the Pierre near the Rocky Mountain Front Range.

The Pierre Shale is the youngest Cretaceous formation in northwestern North Park. Only the lower part of the formation is present because the upper part, as well as younger Cretaceous formation, was eroded during the latest Cretaceous and early Paleocene. The Pierre conformably overlies the Niobrara Formation and unconformably underlies the Coalmont Formation of Paleocene and Eocene age. This usage follows that of Beekly (1915, p. 43–49) for the Pierre in North Park, except that Beekly apparently placed the Pierre-Niobrara contact at a higher stratigraphic position than it is placed in this investigation. The Pierre Shale in northwestern North Park consist predominantly of marine shale, siltstone, and sandstone, and locally a few nonmarine beds. It is divided into two parts: the lower part is called the shaly member; the upper part is called the sandy member. These two members are differentiated on the geologic map, but the contact between the two is not sharply defined and probably does not represent the same stratigraphic horizon throughout the area. The contact between the Pierre and Niobrara is placed in a gradational calcareous sequence at the top of the highest resistant limestone bed in the Niobrara.

Thickness.—The Pierre Shale ranges from an estimated maximum thickness of about 5,000 feet west of Sheep Mountain and Delaney Butte to zero in areas where it was completely eroded away before deposition of the overlying Coalmont Formation. The shaly member, at the base of the Pierre, ranges in thickness from about 3,000 to about 1,700 feet where it is not overlapped by the Coalmont Formation. It is thickest in the north-central part of the area in the vicinity of Lawrence Draw and Dead Horse Draw and thinnest in the Carter Oil Co. Government-McDannald 1 test hole in the northeastern part of the area. Although the data are insufficient, the unit is believed to increase in thickness toward the west.

The thickness of the sandy member of the Pierre Shale is determined by the extent of erosion before deposition of the Coalmont Formation. The member is apparently thickest in the lowland area west of Sheep Mountain and Delaney Butte, where, near the mouth of Bear Creek, it reaches a probable maximum of about 2,200 feet. It is considerably thinner in other areas of exposure.

Distribution and topographic expression.—The Pierre Shale crops out mainly in two north-trending bands on the east and west sides of the Delaney Butte–Sheep Mountain highland. The eastern band extends from the Roaring Fork northward to Independence Mountain and is about ½ to 1½ miles wide. It is considerably obscured in the southern part by Quaternary terrace gravels and alluvium, and elsewhere, by soil and surface wash. The western outcrop band extends irregularly from Roaring Fork northward to the Boettcher Ranch, and the formation extends from there northward at least as far as Goose Creek under a cover of outwash gravel. The western outcrop band is very poorly exposed except near Hell Creek and just south of the Boettcher Ranch; elsewhere it is obscured by gravels, and the only exposures are along banks cut through the gravels. Exposures of small extent are found southwest of Pitchpine Mountain in the southwestern part of the area.

Lithology.—The shaly member, which constitutes the lower part of the Pierre, is almost entirely dark fissile marine shale. The lower 300–900 feet is calcareous shale like that in the upper part of the Niobrara and some of the beds even contain the same white calcareous "specks." The calcareous shale is generally dark gray to brown but weathers light shades of yellow and brown. Above the calcareous shale beds is a sequence of gray to brownish-gray noncalcareous shale about 300 to 400 feet thick which, in the north-central part of the area at least, contains thin beds of bentonite. The next sequence is a dark-bluish-gray noncalcareous shale as much as 600 feet thick. The remainder of the shaly member is gray to brownish-gray shale containing thin rusty siltstone laminae in the lower part and becoming increasingly silty and sandy upward. This sequence is mainly noncalcareous but some of the siltier parts are slightly calcareous. Limestone and noncalcareous siltstone concretions, some of which contain fossils, occur throughout the middle and upper parts of the shaly member but are most abundant in the upper part. Near Lawrence Draw in the north-central part of the area, concretionary masses near the top of the shaly member are as much as 8 feet in diameter and weather out from the soft shale as prominent resistant masses.

The sandy member of the Pierre Shale conformably overlies the shaly member; the contact between the two is in a transitional sequence and is placed where silty or sandy beds above predominate over shaly beds below. This contact is not at the same stratigraphic horizon throughout the area. The sandy member consists of interbedded shale, siltstone, sandstone, silty and sandy shale, and minor amounts of clay-pebble conglomerate, coal, and carbonaceous shale. The even bedding and apparent continuity of the units, as well as the presence of marine fossils, indicate a marine origin for most of the member. A shallow-water environment is indicated for the sandstone beds by the presence of ripple marks, carbonaceous plant material, possible worm-burrow casts, and *Halymenites* which is a fossil that is restricted to brackish- or shallow-water marine beds. Most of the sandstone beds are noncalcareous, but the more resistant beds apparently have a calcium carbonate cement. Clay-pebble conglomerate is locally conspicuous as in the area between Spring Gulch and Hell Creek and in the area on the west side of Sheep Mountain about 1 mile northwest of the Fliniau Ranch. The matrix sand of the conglomerate is similar to other sandstone of the sandy member but contains irregularly shaped fragments of greenish-gray clay in the form of grains, pebbles, pods, and stringers. A shallow-water marine origin is indicated. A fossil shark tooth was found in a conglomerate bed north of the Fliniau Ranch.

A coaly sequence, possibly as much as 75 feet thick in the vicinity of the old Monahan coal mine west of the northern part of Sheep Mountain is the only clearly nonmarine part of the sandy member; even so, the coaly beds are interbedded with shallow-water marine sandstone beds. Coal was not found in the Pierre elsewhere in the area, and apparently the coaly zone thins and disappears toward the east.

The following composite stratigraphic section, measured in the area between Lawrence Draw and Dead Horse Draw, shows the lithology of the Pierre Shale in the north-central part of the area:

Composite section of the Pierre Shale in N½ sec. 16, SE¼ sec. 9, W½ and NE¼ sec. 10, T. 10 N., R. 81 W.

Coalmont Formation:	
Sandstone, light-gray, coarse-grained, feldspathic, nonresistant; contains pebbles of crystalline Precambrian rock.	
Pierre Shale:	
Sandy member:	*Feet*
Shale, gray, silty to sandy, slightly calcareous, thin-bedded to laminated; contains a few limestone concretions; basal 1 ft is a zone of noncalcareous rusty-brown ironstone concretions	22
Shale, gray, silty to sandy, slightly calcareous, thin-bedded to laminated; contains a few limestone concretions	51
Sandstone, brownish-gray, very fine grained, calcareous; includes a few beds of shale	12
Poorly exposed; mostly gray silty shale, slightly calcareous; contains a few limestone concretions	49
Shaly member:	
Poorly exposed; apparently all gray noncalcareous shale; contains a few limestone concretions	92
Offset along the strike about 0.1 mile to the south	
Shale, gray, noncalcareous, thin-bedded to laminated; weathers fissile; this unit contains the most conspicuous occurrence of limetone concretionary masses which form "tepee butte" structures in the nonresistant shale; concretions range from about 1 to 8 ft in diameter; limestone is brownish gray, weathers light brownish, is highly fractured, breaks up into irregular, angular pieces as much as about 1 ft in length, and is dense and hard; concretions occur throughout unit and do not follow any horizon	119
Poorly exposed; mostly gray, noncalcareous shale	45

Offset along the strike about 0.2 mile to the south

	Feet
Pierre Shale—Continued	
Shaly member—Continued	
Poorly exposed; mostly gray shale; contains a few limestone concretions	114
Covered; material from animal burrows near top of unit consists of gray, brown-weathering shale; float in upper part of unit contains chips of gray, yellow-weathering, slightly calcareous siltstone	71

Offset along the strike about 0.2 mile to the south

	Feet
Poorly exposed; mostly gray shale; weathers mottled brown and gray	81
Covered; fragments of limestone concretions in float about 27 ft above base of unit	42
Covered; material from animal burrows near top of unit consists of fissile gray silty shale; float contains a few chips of rusty slightly calcareous siltstone	105

Offset along the strike about 0.2 mile to the south

	Feet
Shale, gray, noncalcareous; interbedded with minor thin beds of rusty slightly calcareous silty shale	83
Covered; surface wash contains weathered brown shale and calcareous siltstone chips about 110 ft above base	170
Covered; abundant float of slightly calcareous siltstone chips	11
Covered to poorly exposed; probably mostly gray noncalcareous shale and minor thin interbedded siltstone	327
Covered; surface wash indicates mostly soft, gray shale; sparse limestone concretion rubble in float about 100 ft above base	306
Poorly exposed; mostly gray shale interbedded with sparse siltstone	50
Shale, gray, interbedded with minor thin beds of rusty slightly calcareous silty shale as much as 1 ft thick	47
Shale; upper and lower parts are rusty slightly calcareous silty shale; middle part is noncalcareous gray shale; basal ½ ft contains zone of selenite crystals	7
Shale, medium-gray to dark-bluish-gray; contains a few thin beds of grayish-brown shale	22
Poorly exposed; zone of limestone concretions; broken pieces as much as 1 in. long; probably in gray shale	5
Shale, dark-bluish-gray; contains a few thin beds of grayish-brown shale; basal bed is rusty-brown silty shale containing selenite crystals	10
Poorly exposed; mostly bluish-gray shale, interbedded with a few thin beds of grayish-brown shale	83
Limestone concretion zone; limestone is light grayish brown mostly fractured, hard, and dense; largest concretions are 2 ft in diameter; forms obscure but persistent ridge at this locality	8
Poorly exposed; mostly medium-gray shale, interbedded with minor beds of bentonitic shale or bentonite; bentonitic beds are soft and nonresistant; form persistent depression bands along strike	115

Pierre Shale—Continued	
Shaly member—Continued	*Feet*
Shale, medium-gray; weathers mottled brown and gray; thin bentonite bed at top	52
Poorly exposed; mostly medium-gray shale; weathers mottled brown and gray; contains some thin beds and stringers of bentonite	94
Poorly exposed; mostly medium-gray to brownish-gray shale; thin bentonite bed 17 ft above base	38
Offset along the strike about 0.1 to the south	
Poorly exposed; mostly light-gray to grayish-brown calcareous speckled shale	226
Covered; surface wash is yellow-weathering calcareous speckled shale	253
Offset along the strike about 0.2 mile to the south	
Covered; surface wash indicates gray to yellowish-gray, yellow-weathering, calcareous speckled shale; Surface wash contains very sparse fragments of *Inoceramus*; base of unit taken at obscure topographic break assumed to be resistant limestone bed at top of Niobrara Formation	479
Total preserved, Pierre Shale	3, 189
Niobrara Formation:	
Covered.	

The following stratigraphic section of the Pierre was measured along the north bank of the North Fork of the North Platte River in the central part of the area:

Section of the Pierre Shale

[Upper 2,150 ft (approximately) measured in S½ sec. 12, T. 9 N., R. 81 W.; lower 1,100 ft (approx.) measured in SE¼ sec. 11, T. 9 N., R. 81 W.]

Coalmont Formation:	*Feet*
Conglomeratic sandstone, gray to light-grown, rusty-brown weathering; at base is a layer of pebbles and cobbles as much as about 3 in. in length; overlying this is coarse feldspathic sandstone containing scattered small pebbles; pebbles and cobbles are mostly Precambrian instrusive and metamorphic rocks, and include a scattering of hard sandstone from the Dakota.	
Pierre Shale:	
Sandy member:	
Shale and minor interbedded siltstone; shale is light gray; siltstone is rusty brown and slightly calcareous; entire unit nonresistant	15
Covered; surface wash indicates dark shale alternating with nonresistant sandstone	725
Shale, medium-gray	6

Pierre Shale—Continued	
Sandy member—Continued	*Feet*
Sandstone, gray, brownish-gray weathering, fine- to medium-grained; interbedded resistant and nonresistant thin ledge-forming beds; contains abundant dark grains; hard beds are calcareous; bedding not apparent in nonresistant parts, even and thin bedded in resistant parts; weathered bedding surfaces contain some ripple marking and some markings that are possibly worm-burrow casts; top of unit resistant, ledge forming	14
Covered; surface wash indicates mostly nonresistant sandstone and some thin resistant sandstone	40
Sandstone, brownish-gray, light-brown weathering, fine- to medium grained, calcareous, well-cemented; contains abundant dark grains giving the rock a salt-and-pepper appearance; contains sparse disseminated and lenticular clay-pebble conglomerate; bedding obscure but some parts are even and thin bedded; resistant; forms low hogback ridge locally, but ridge is not persistent laterally	20
Sandstone, light-gray, light-brownish-gray weathering, very fine grained; contains fairly abundant dark grains; bedding not apparent; nonresistant	90
Poorly exposed; mostly light-gray slightly calcareous thin-bedded to laminated siltstone; weathers to fissile or platy fragments; nonresistant	55
Shaly member:	
Poorly exposed; mostly light-brown to gray shale that weathers mottled gray and brown; noncalcareous in lower part becoming slightly calcareous upward and increasing in silt content; nonresistant; contains numerous very thin calcareous rusty silstone beds; also contains noncalcareous siltstone and silty limestone concretionary masses; unit becomes increasingly silty upward; contains abundant selenite crystals on weathered outcrops in upper part; contains fossil shells at top of unit in siltstone concretions (USGS Mesozoic loc. D988 *Baculites asperiformis* Meek)	415
Shale, brownish-gray, slightly silty; upper part, calcareous; contains very thin slightly calcareous rusty siltstone beds; base of unit taken at siltstone bed that is brownish gray, light brown weathering, noncalcareous, and hard and that forms resistant lenticular ledge; siltstone bed reaches a maximum thickness of 8 ft	248
Shale, medium-gray to brownish-gray, noncalcareous; contains very thin slightly calcareous rusty siltstone beds; base of unit taken at 1-ft-thick siltstone bed that is light brown, noncalcareous, laminated, hard, dense, and ledge forming	220
Poorly exposed; mostly dark-gray to dark-bluish-gray shale that weathers mottled brown and gray and that is noncalcareous fissile, and nonresistant; contains numerous very thin slightly calcareous rusty siltstone beds	575

Pierre Shale—Continued	
Shaly member—Continued	*Feet*
Poorly exposed; mostly dark-gray to dark-brownish-gray, grayish-brown weathering noncalcareous fissile shale; contains very thin slightly calcareous rusty siltstone beds; entire unit nonresistant	285
Covered to poorly exposed; upper part appears to be mostly brown and gray, yellowish-gray weathering, mainly noncalcareous fissile shale; probably contains some silty beds; lower part appears to be light-brown, brownish-yellow weathering calcareous fissile shale; entire unit nonresistant	193
Poorly exposed; mostly light-brown calcareous thin-bedded shale; streaks of gray; weathers yellowish brown; weathers to fissile or blocky chips	228
Shale, grayish-yellow to grayish-brown, light-grayish-yellow weathering, calcareous, speckled, marly; obscurely thin to massive beds alternate with laminated fissile-weathering beds; lower part is increasingly calcareous downward, weathers yellow, and weathers to fissile or blocky fragments; entire unit nonresistant	139
Total preserved Pierre Shale	3,268
Niobrara Formation:	
Smoky Hill Shale Member:	
Limestone, very light brownish yellow, yellowish-white weathering, chalky, thin to irregularly bedded; resistant, ledge-forming; contains *Ostrea* and fragments of *Inoceramus*.	

Correlation.—The Pierre Shale of northwestern North Park occupies the same stratigraphic position as the Pierre Shale of eastern Colorado and the eastern foothills of the Front Range. The Pierre of northeastern Colorado has been subdivided by most workers into a lower unit consisting predominantly of dark shale; a middle unit consisting of interbedded sandstone and shale; and an upper unit consisting predominantly of shale, sandy shale, and a minor amount of sandstone. The lower unit includes the Sharon Springs zone and Rusty zone as used by Griffitts (1949, p. 2013–2017). The middle unit is generally known as the Hygiene zone and contains five named sandstone members that contain distinctive marine invertebrate fossils (Scott and Cobban, 1959, p. 126–129). These sandstone members are, in ascending order, Hygiene, Terry, Rocky Ridge, Larimer, and Richard.

The shaly member of the Pierre of northwestern North Park is correlated with the lower shaly unit of the Pierre of eastern Colorado. The sandy member is correlated with that part of the so-called Hygiene zone of the northern Front Range from the Hygiene Sandstone Member up to and including the Larimer Sandstone Member (Kinney and Hail, 1959, p. 108). This correlation assumes that the uppermost beds of the Pierre of northwestern North Park are at the same stratigraphic horizon as the uppermost beds of the Pierre in eastern North Park. These highest beds in eastern North Park yielded the fossil ammonite *Acanthoscaphites nodosus* (Owen) which is found in the Larimer Sandstone Member of northeastern Colorado (Scott and Cobban, 1959, p. 128). The cephalopod *Baculites asperiformis* was found in the uppermost beds of the shaly member in the section measured along the North Fork of the North Platte River in the SE¼ sec. 12, T. 9 N., R. 81 W. (USGS Mesozoic loc. D988). *B. asperiformis* is found in the shale underlying the Hygiene Sandstone Member of the Pierre in northeastern Colorado (Scott and Cobban, 1959, p. 129). Other marine invertebrate fossils were found in the sandy member of the Pierre at various localities in northwestern North Park but none is diagnostic in determining the correlative zone in the Pierre of eastern Colorado. Fossils of *Baculites* sp. were found in beds overlying the coal zone in the vicinity of the old Monahan coal mine, in the SE¼ sec. 31, T. 10 N., R. 81 W. (USGS Mesozoic loc. D1117). Cobban reported (written commun., 1956): "The baculites suggest an undescribed species that occurs in the lower part of the Hygiene Sandstone of the Denver area."

The absence from the Pierre in northwestern North Park of beds higher than the equivalent of the Larimer Sandstone Member indicates that pre-Tertiary erosion removed the upper part of the Pierre and probably removed strata equivalent to the Fox Hills Sandstone, Laramie Formation, and the Arapahoe Formation of the Front Range area. These rocks aggregate as much as 8,300 feet in thickness in northeastern Colorado (Mather, Gilluly, and Lusk, 1928, p. 76–77).

In the Laramie Basin, Wyo., the Steele Shale is the probable equivalent of the shaly member of the Pierre of northwestern North Park, and the Mesaverde Formation is the equivalent of the sandy member. However, beds equivalent to the uppermost part of the Mesaverde have been eroded from northwestern North Park.

In northwestern Colorado the equivalents of the shaly member of the Pierre Shale of northwestern North Park are correlative with that part of the Mancos Shale above the Niobrara equivalent and below the Iles Formation of the Mesaverde Group. Equivalents of the sandy member of the Pierre of northwestern North Park are probably correlative with the Iles Formation and the lower part of the Williams Fork Formation, both of the Mesaverde Group.

The Iles and Williams Fork Formations of the Mesaverde Group consist of mixed marine and nonmarine rocks including sandstone, sandy shale, shale, and numerous thick coal beds. The Mesaverde Group of northwestern Colorado and its correlatives elsewhere, including the so-called Hygiene zone of northeastern Colorado, compose an eastward-thinning tongue, predominantly of sandstone, deposited shoreward of an eastward-retreating Cretaceous sea. Weimer (1960, p. 6–8, fig. 3) demonstrated that the Mesaverde and Hygiene zone sequence was deposited during the third of four major Late Cretaceous regressions. Nonmarine beds are abundant in the Mesaverde of northwestern Colorado, but only marine beds are present in the so-called Hygiene zone of northeastern Colorado. The sandy member of the Pierre of northwestern North Park apparently contains the easternmost thin wedge of nonmarine beds of the Mesaverde and Hygiene zone sequence. These are the thin coaly and carbonaceous beds known only in the outcrop area near the old Monahan coal mine west of Sheep Mountain. Zapp and Cobban (1960) showed that there are lesser transgressive-regressive cycles within the major Mesaverde regression of northwestern Colorado. The coaly nonmarine beds of northwestern North Park probably represent the eastern extent of the regression designated by Zapp and Cobban (1960, p. B. 248) as the "Middle Iles–Palisade" regression. Marine invertebrate fossils show that this regressive zone and the coaly zone in northwestern North Park are approximately correlative.

TERTIARY SYSTEM

PALEOCENE AND EOCENE SERIES

COALMONT FORMATION

Definition.—Beekly (1915, p. 50), in naming the Coalmont Formation, stated: "* * * 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." Coalmont, formerly a small village but now virtually uninhabited, is about 4 miles south of the area. Beekly did not measure a detailed lithologic section in the type area.

Geologists of the Army's 40th Parallel Survey (King, 1876, map 1; Hague and Emmons, 1877, p. 127–129) applied the name North Park Tertiary or North Park Group to all Tertiary sedimentary rocks in North Park, including the Coalmont Formation as now recognized.

Geologists of the Territorial Surveys (Hayden, 1868) used the terms "Laramie" or "lignitic" for Tertiary beds in southern North Park now recognized as the Coalmont Formation. Marvine (1874, fig. 8, p. 156–157) mapped shales, sandstones, and conglomerate beds in Middle Park, and recognized that they extend across the divide into North Park. He designated these strata as the "lignitic formation" and stated his belief that they were Cretaceous or Eocene in age. Hayden (1876, p. 19–27; 1877) believed that Marvine's "lignitic formation" correlated with the Laramie Formation, and he designated these beds as Laramie in Middle Park and southern North Park. He believed the age of these beds to be Tertiary.

Cross (1892, p. 27–31) examined the Laramie or lignitic beds of Hayden and Marvine in Middle Park and rejected the correlation with the Laramie. He showed the rocks to be post-Laramie in age and substituted the name Middle Park. Cross did no geologic mapping in Middle or North Parks but it is presumed that he intended the name Middle Park to apply to all the beds that Marvine had designated "lignitic formation" including those in southern North Park. The name Middle Park Formation is now used in Middle Park for these Tertiary rocks and has been applied to strata which are at least in part correlative with the Middle Park Formation in North Park and now more commonly referred to as Coalmont Formation.

Beekly's definition (1915) of the Coalmont Formation is essentially followed in this report. The Coalmont consists of heterogeneous fresh-water fluvial and swamp deposits of Paleocene and Eocene age unconformably underlying the White River Formation of Oligocene age and the North Park Formation of late Miocene age and unconformably overlying various formations of Cretaceous age. The name Coalmont has not generally been used for correlative strata outside North Park. In the Coalmont area a few miles south of the mapped area, a conspicuous unconformity separates the Paleocene part of the formation from the Eocene part. The unconformity, however, could not be traced northward into the mapped area, and no attempt was made to draw a boundary between the Paleocene and Eocene parts of the formation.

Thickness.—The maximum original thickness of the Coalmont Formation is not known. In most of its outcrop area, the Coalmont is not overlain by younger formations, and its upper part is assumed to have been removed by erosion. In the Carter Oil Co. Government-McDannald 1 test hole in the SE¼ sec. 4, T. 10 N., R. 80 W., about 3,400 feet of Coalmont strata is apparently present. A partial exposed section of the Coalmont measured in T. 10 N., Rs. 80 and 81 W., has a thickness of about 5,200 feet. As measured or estimated from gentle dips across distances of several miles, the Coalmont may be about 7,000 feet thick in the southern part of the area, between the mouth of Butler Creek and Peterson Ridge; however, because the lower beds of the Coalmont may wedge out against buried hills, the Coalmont may locally be thinner.

Distribution and topographic expression.—The Coalmont Formation forms the surface rock for much of the lowland part of the area. The main outcrop area lies east of the Delaney Butte-Sheep Mountain highland and south of the Roaring Fork and extends from Independence Mountain southward to Peterson Ridge and westward 5 to 7 miles from Peterson Ridge. In the southern part of this area, the formation is extensively overlain by terrace gravels and alluvium. Smaller areas of outcrop lie on the west slopes of Delaney Butte and Sheep Mountain.

The Coalmont Formation is generally nonresistant and poorly exposed; but it is more resistant than the underlying Pierre Shale, and the basal beds form a low but distinct ridge along the Pierre-Coalmont boundary in the northeastern part of the area. Where cemented by calcite, sandstone and conglomerate beds are fairly resistant and form low generally discontinuous ridges. The best exposures of the Coalmont are found along streambanks, especially in the southern part of the area along Raspberry Creek, Beaver Creek, and Manville Draw.

Sub-Coalmont unconformity.—At all observed exposures of its basal contact, the Coalmont Formation lies with obvious unconformity on underlying rocks. Northward from the vicinity of the Wattenberg Ranch (sec. 13, T. 9 N., R. 81 W.), the Coalmont very gradually overlaps progressively older beds of the sandy member of the Pierre Shale. In sec. 3, T. 10 N., R. 81 W., the Coalmont lies on the shaly member of the Pierre. In the gravel- and alluvium-covered area between Peterson Ridge and Delaney Butte, the Coalmont apparently successively overlaps the Pierre Shale, the Niobrara Formation, and probably the Benton Shale in a buried structural and topographic high. West of Sheep Mountain and Delaney Butte and east of Pitchpine Mountain, the Coalmont overlaps steeply folded and truncated Mesozoic rocks. About 1 mile south of Pitchpine Mountain it lies on rocks of the Dakota Sandstone. East of Lake John, in exposures nearest the center of the basin, the dips of the Coalmont and the underlying Pierre Shale are almost parallel; but west of Sheep Mountain, near the abandoned Monahan coal mine, the dips diverge as much as 66°.

Lithology.—The Coalmont Formation is a heterogeneous mixture of rock types including conglomerate, conglomeratic sandstone, claystone, and carbonaceous shale. Its coarse detrital constituents are mostly quartz, feldspar, dark minerals, and rock fragments presumably derived mostly from Precambrian granitic and metamorphic rocks in the adjacent highlands.

Figure 8 shows a partial composite section of the Coalmont Formation measured across a distance of about 5 miles in various parts of T. 10 N., Rs. 80 and 81 N., and is representative of the lithology in the northeastern part of the area. Here the Coalmont is about 5,200 feet thick and consists of a monotonous sequence of alternating conglom-

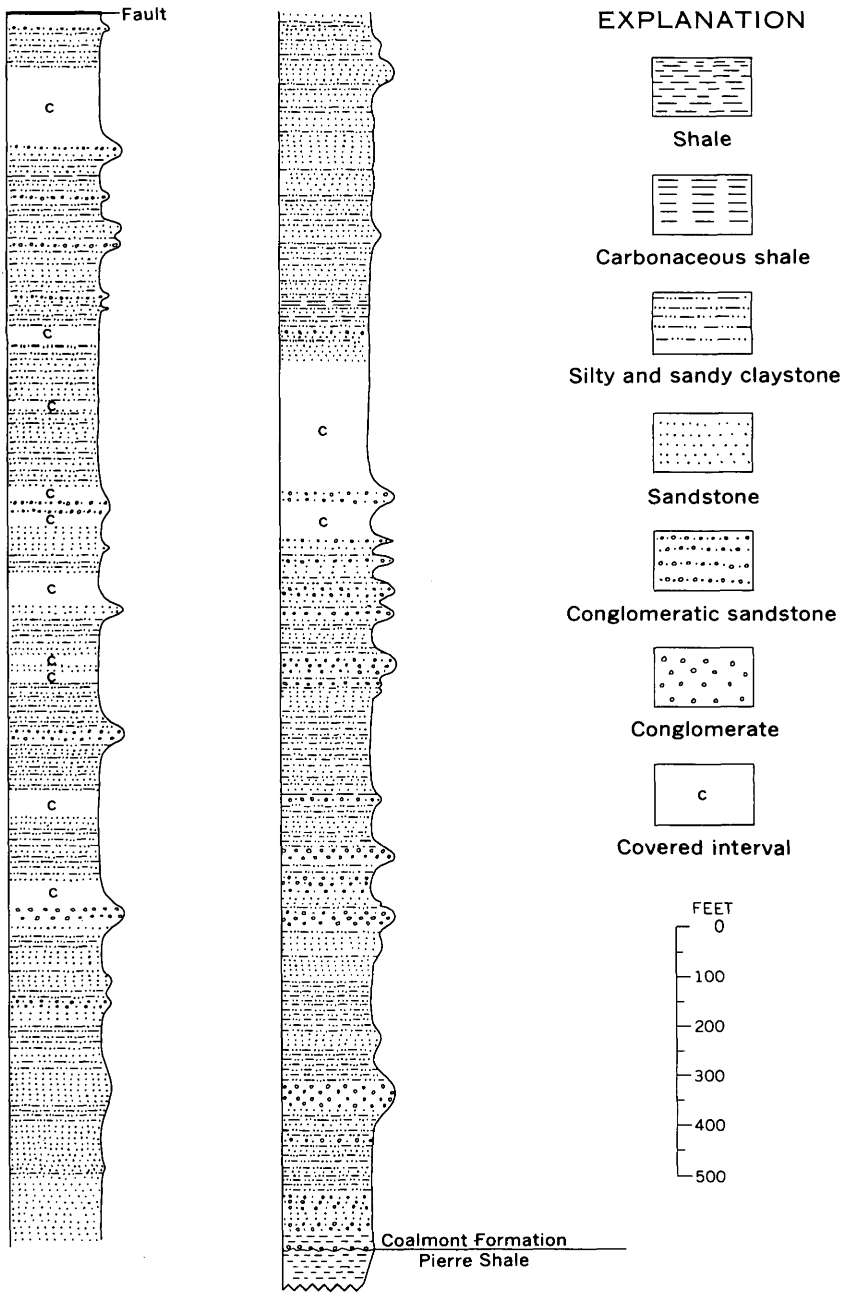

FIGURE 8.—Partial composite section of the Coalmont Formation in the northeast part of the area.

erate, conglomeratic sandstone, sandstone, claystone, and a few thin carbonaceous shale beds. Poorly preserved carbonaceous wood is scattered throughout the section.

Farther south, in the vicinity of Alkali Lake, in sec. 6, T. 9 N., R. 80 W., the lower part of the Coalmont contains a zone of carbonaceous shale as much as 400 feet thick. About 5 miles farther southeast, in the southeastern part of T. 9 N., R. 80 W., other beds or zones of carbonaceous shale appear higher in the formation and are as much as 440 feet thick. From this vicinity southward to Peterson Ridge, the upper 1,000 to 1,200 feet of the Coalmont consists mostly of nonresistant, easily eroded beds of sandstone and claystone. In some places, as in the NE¼ sec. 34, T. 11 N., R. 81 W., coaly and carbonaceous clay beds of the Coalmont immediately overlie an apparent soil zone developed on gray shale beds of the Pierre Shale.

In the outcrop area extending from Peterson Ridge westward for several miles, carbonaceous shale is a minor constituent except for the lower 1,000 feet of the formation, which contains a carbonaceous shale zone as much as 400 feet thick. This carbonaceous shale zone contains the Mitchell coal bed of Beekly (1915, p. 107), in sec. 24. T. 8 N., R. 82 W. The remainder of the Coalmont in this southern outcrop area is a sequence of conglomerate, conglomeratic sandstone, sandstone, and claystone several thousand feet thick.

Gravelly beds compose a large proportion of the Coalmont Formation and are designated either conglomerate or conglomeratic sandstone depending on the relative proportions of gravel and sand. Only in the lower 1,200 feet of the formation do any of the conglomerate beds have much lateral continuity; most of them do not exceed a mile or two in length. The gravel constituents range from pebbles to small cobbles in size (fig. 9); however, conglomerate at the base of the formation locally contains boulders as large as 15 inches long. The gravel is composed almost entirely of quartz, feldspar, and fragments of Precambrian crystalline rocks but contains sparse chert and hard sandstone fragments apparently derived mostly from rocks of the Dakota Sandstone. The larger pebbles and cobbles commonly are rounded, and the smaller pebbles are angular to subrounded. The sand matrix consists of quartz, feldspar, biotite, hornblende, fragments of Precambrian crystalline rocks, and sparse grains of sedimetary rock. Sorting is poor to fair; the grain size ranges from very fine to coarse, but medium to coarse sizes predominate. The sand grains are mostly angular; very few show any rounding. The conglomeratic beds include some of the most resistant units in the formation, but in general they are poorly cemented. A weak clay cement gives some coherence to many of the beds, but the only resistant ledge- or ridge-forming beds are those cemented by calcite. The calcite cement is irregularly distributed and in many places is confined to lenses within single beds. The conglomeratic beds are mostly massive, but some are considerably crossbedded. The conglomerate is predominantly brown and gray where fresh and yellow or rusty-brown where weathered.

FIGURE 9.—Conglomerate in basal beds of the Coalmont Formation in roadcut west of Sheep Mountain in the NE¼ sec. 8, T. 9 N., R. 81 W. Gravel consists almost entirely of waterworn Precambrian crystalline rocks. Matrix is coarse sandstone.

Sandstone beds of the Coalmont Formation differ little from the sand matrix of the conglomeratic beds and grade vertically and horizontally into the conglomerates. The sandstone is an arkose or subarkose, composed mostly of quartz, feldspar, biotite, hornblende, and fragments of Precambrian crystalline rocks, all of which are apparently derived from the Precambrian rocks of the bordering highlands. Sparse fragments of sedimentary rocks are found locally. Seven thin sections of representative samples contained the following percentages of the major detrital constituents:

Mineral	*Percentage range*	*Average percentage*
Quartz	39–60	48
Feldspar	12–34	20
Biotite	4–22	13
Hornblende	4–18	8
Rock fragments	0–17	7
Others	----------	4

The sandstone beds are for the most part poorly cemented and nonresistant. Many have a weak clay cement, but locally a few are firmly cemented by calcite and form lenticular resistant ledges and ridges (fig. 10). The sand is poorly sorted, generally ranging in size from fine to very coarse; most of it is coarse grained. Most grains are angular. Much of the sandstone is massive or irregularly bedded (fig. 10); crossbeds are common in most of the sandstone; even bedding is present locally. The sandstone is various shades of brown and gray where fresh and yellow or rusty brown where weathered.

Just north of Delaney Butte in the W½ sec. 34, T. 9 N., R. 81 W., a wedge of arkosic rocks in a fault slice has been thoroughly cemented into a granitelike rock, presumably by solutions that rose along one of the faults. Thin-section examination shows it to be a clastic rock cemented by quartz. The rock is very hard and resistant and forms a conspicuous ridge adjacent to the faults.

This arkose has been mapped as part of the Coalmont Formation and designated Coalmont(?) Formation on the map; its true assignment is in doubt. It possibly was derived locally from nearby Delaney Butte after the formation of the thrust fault to the west but before the formation of the thrust fault on the east which cuts the arkose. Thus the arkose may be younger than true Coalmont, possibly as young as late Miocene or Pliocene.

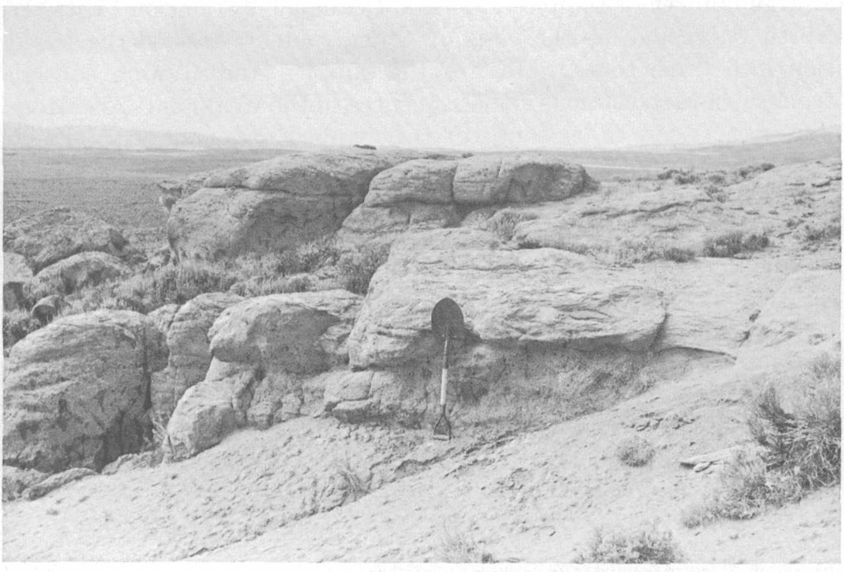

FIGURE 10.—Resistant massive to irregularly bedded sandstone in the upper part of the Coalmont Formation in the NW¼ sec. 21, T. 10 N., R. 80 W. Ledge-forming sandstone beds such as these generally have a calcium carbonate cement.

Claystone beds make up a large proportion of the Coalmont Formation. As here used, claystone is a nonfissile rock that is a mixture of clay and silt in various proportions. It commonly contains sparse to abundant, fine to very coarse quartz and feldspar grains, and locally small pebbles. The claystone is mainly pale green, gray, and brown; at a few places it is red, and at some places it is mottled. Its colors generally contrast sharply with the relatively drab colors of the sandstone and conglomerate beds. The claystone is nonresistant and easily eroded. Most of the claystone is noncalcareous, but some of the more sandy beds contains sparse calcite.

Carbonaceous shale beds are locally abundant in the Coalmont and are characteristically soft, fissile, and light brown to dark chocolate brown. The color is imparted by abundant carbonized plant material, which locally forms coaly streaks.

Correlation.—Fossil pollen shows the upper part of the Coalmont Formation to be Eocene in age (Hail and Leopold, 1960). Previously, fossil leaf collections had indicated an equivalence in age entirely or in part to the Fort Union Formation of Paleocene age (Beekly, 1915, p. 62–63; Brown, 1949). R. W. Brown (written commun., 1958) suggested that a collection of fragmentary fossil leaves from a bed of shaly sandstone in the upper part of the Coalmont Formation might be younger than Paleocene.

Estella B. Leopold (written commun., 1958, 1959, 1961) examined a large number of samples from the Coalmont Formation of western North Park, and, on the basis of pollen content, divided the formation into three zones. Most of the samples studied were collected from thick carbonaceous shale sequences in the Coalmont-Pole Mountain area, a few miles south of the mapped area, but many of the samples came from within the mapped area.

Pollen zone 1, the lowest, is Paleocene in age; pollen zones 2 and 3 are Eocene in age and probably early Eocene. Zone 1 contains pollen common to the Paleocene and Eocene, but contains no forms restricted to Eocene or younger rocks. Zones 2 and 3 contain characteristic Eocene pollen forms not known in rocks older than Eocene. The two zones are differentiated on the basis of the relative abundance of certain of these forms.

Eocene and younger pollen includes:

Eucommia cf. *E. ulmoides* (Eucommiaceae)
Platycarya cf. *P. strobilacea* (Juglandaceae)
cf. *Juglans* (Juglandaceae)
Tilia (Tiliaceae)
Tsuga cf. *T. canadensis* (Pinaceae)
cf. *Fremontia* (Sterculiaceae)
cf. *Alangium* (Alangiaceae)
cf. *Vaccinium* (Ericales)

Eocene and Paleocene forms include:

cf. *Platycarya* (morphologically distinct from *P. strobilacea;* Juglandaceae type)
Carya (Juglandaceae)
Pistillipollenites (form genus)
Zelkova, Ulmus (Ulmaceae)
cf. *Tsuga mertensiana*

Miss Leopold established the three Coalmont pollen zones using the following criteria:

Coalmont 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.

Coalmont pollen zone 2 (Eocene): Several Eocene and younger forms appear in small numbers—*Platycarya* cf. *P. strobilacea, Tilia* and *Eucommia. Platycarya* increases from 5 to 10 percent of the total pollen in the basal samples to 16 percent at the top.

Coalmont pollen zone 3 (Eocene): All Eocene and younger forms are more common. *Platycarya* cf. *P. strobilacea* increases from 27 percent in the basal sample to 40 percent in higher samples. *Eucommia* is 5 to 7 percent of the count, and *Tilia* is 1 to 2 percent.

Only one sample collected within the mapped area is assigned to pollen zone 1 (Paleocene age). This sample, collected at USGS paleobotanical locality D1358 in the NE¼ NW¼ sec. 32, T. 8 N., R. 81 W., came from a bed of brown claystone estimated to lie about 2,600 feet stratigraphically above the base of the Coalmont Formation and about 2,100 feet below a carbonaceous shale bed that contains pollen of Eocene age at USGS paleobotanical locality D1580.

Samples from the following localities are assigned to pollen zone 2 (Eocene).

USGS paleobotanical locality		*Location*		
		Sec.	*T.N.*	*R.W.*
D1572–A	NE¼SW¼	21	10	80
D1572–B	NE¼SW¼	21	10	80
D1573–A	SW¼SE¼	6	9	80
D1573–B	SE¼SE¼	6	9	80
D1574–A	SW¼SW¼	18	9	80
D1574–B	SW¼SW¼	18	9	80
D1575	NE¼NW¼	19	9	80
D1576	NW¼NE¼	5	8	80
D1577	NW¼NW¼	4	8	80
D1578	SW¼NE¼	4	8	80
D1580	NE¼SW¼	22	8	81
D1581	SW¼NE¼	22	8	81
D1582	NE¼NE¼	22	8	81

Samples from localities D1574–A and D1574–B were taken from carbonaceous shale beds estimated to lie only about 500 feet stratigraphically above the base of the Coalmont Formation. The stratigraphically highest samples in pollen zone 2 were found at locality D1572–A in the northeastern part of the area and at locality D1582 in the southern part of the area—about 4,900 feet and 5,400 feet respectively above the base of the Coalmont Formation.

Only one sample representing pollen zone 3 (Eocene) was collected within the mapped area. This sample, collected at USGS Paleobotanical locality D1583 in the SW¼ sec. 14, T. 8 N., R 81 W., was taken from a bed of carbonaceous shale estimated to be about 5,800 feet stratigraphically above the base of the Coalmont Formation, and about 250 feet above a bed in pollen zone 2.

In the Coalmont-Pole Mountain area just south of the mapped area, rocks representing pollen zone 1 are separated from rocks containing pollen zones 2 and 3 by an unconformity. In that area the unconformity provides an easily mapped boundary between the Paleocene and Eocene parts of the formation, but it could not be traced into the mapped area. Although there is no clear lithologic basis for dividing the Coalmont in the map area, the pollen data suggest that strata of Paleocene age are confined to the area west of a line along the crest of the Sheep Mountain-Delaney Butte highland and west of a line roughly bisecting T. 8 N., R. 81 W., between Roaring Fork and the south boundary of the area.

According to Miss Leopold (written commun., 1961), certain of the Eocene and younger pollen forms of zones 2 and 3 are also found in the following formations: The Clarno Formation (Eocene age), Oregon; the Tipton Tongue (late early Eocene age) of the Green River Formation, southwestern Wyoming; Wasatch Formation (early Eocene age) immediately under the Tipton Tongue, southwestern Wyoming; and the Kingsbury Conglomerate Member (early Eocene age), northern Wyoming.

The Middle Park Formation in Middle Park, Colo., is continuous in part with the Coalmont Formation of North Park, although the exact stratigraphic relations are not known. Knowlton (1930, p. 6) correlated the Middle Park Formation with the Denver Formation on the basis of fossil leaves, which in the Denver Formation are considered to be Paleocene in age. Thus the Coalmont Formation is correlative in part with both the Middle Park and Denver Formations.

In the Laramie Basin, Wyo., rocks equivalent in age to the upper part of the Coalmont Formation include the Hanna and Wind River Formations of Eocene age. Rocks of Paleocene age, correlative with the lower part of the Coalmont, apparently are not present in the Laramie Basin.

In northwestern Colorado, west of the Park Range, rocks equivalent in age to the Coalmont Formation include the Fort Union Formation of Paleocene age and the Wasatch Formation of Eocene age (Bass, Eby, and Campbell, 1955, p. 161).

OLIGOCENE SERIES

WHITE RIVER FORMATION

Definition.—Meek and Hayden (1856, p. 119,) first used the name White River, applying it to beds near the mouth of the White River in present South Dakota. In South Dakota, Nebraska, and southeastern Wyoming, the White River is regarded as a group and is divided into two lithologically distinct formations—the Chadron Formation of early Oligocene age and the Brule Formation of middle and late Oligocene age. West of the Laramie Range in Wyoming, however, equivalents of the Chadron and Brule Formations are not lithologically separable and are mapped as the White River Formation (McGrew, 1953, p. 63). Outcrops of lower Oligocene rocks in the Kings Canyon area of northeastern North Park were reported by McGrew (1953, p. 63) and by Knight (1953, p. 69, 71, pl. 7). Steven (1954) at first assigned these rocks to the White River Group, but later he (Steven, 1956, p. 40–41; 1957, p. 337, pl. 48; 1960, p. 350–352) applied the name White River Formation to them. In 1955 Montagne (Montagne and Barnes, 1957, p. 56) recognized the White River Formation in the Peterson Ridge area of central North Park. These beds had been included in the lower part of the North Park Formation as redefined by Beekly (1915, p. 66).

In this report the name White River Formation is applied to the rocks of Oligocene age in the Peterson Ridge area and to rocks of similar lithology in the Pearl area. In the Peterson Ridge area the White River unconformably underlies the North Park Formation of probable late Miocene age and unconformably overlies the Coalmont Formation of Paleocene and Eocene age. The base of the formation at Peterson Ridge coincides with the base of the North Park Formation as redefined by Beekly (1915).

Lithology.—Montagne and Barnes (1957, p. 56) divided the White River Formation into two units: a lower unit consisting of an alternating sequence of white sandstone, conglomerate, and reddish-brown and green shale, all of which were derived from Precambrian rocks; and an upper unit consisting of massive white tuffaceous siltstone and claystone. The author places the lower unit of Montagne and Barnes in the top part of the Coalmont Formation.

Little of the White River Formation can be seen within the mapped area inasmuch as it is mostly covered and is represented only by a wedge not more than 230 feet thick on the lower slopes of Peterson Ridge at the east edge of the area. Outcrops farther east appear to consist of light-colored fine-grained ashy sandstone and claystone. These rocks rest on conglomerate of the Coalmont Formation.

Light-gray silty claystone near Pearl, in the extreme northwestern part of the area, is exposed in small isolated outcrops and rests on Precambrian metamorphic rocks; it is assigned to the White River Formation. It closely resembles the fossiliferous claystone of the White River Formation in Kings Canyon, about 16 miles to the east.

Correlation.—The White River Formation of the Peterson Ridge and Pearl areas is correlated with the White River Formation cropping out in Kings Canyon in the Northgate area of northeastern North Park and with the lower part of the White River Formation of the Laramie Basin, Wyo. An early Oligocene (Chadronian) age was assigned by McGrew (1953 p. 63) and by Knight (1953, p. 71) to the White River in the Kings Canyon area. Beds of middle and late Oligocene (Brule) age are not present. Montagne (Montagne and Barnes, 1957, p. 56) discovered a fossil titanothere tooth of early Oligocene age in the Peterson Ridge area of central North Park in sec. 15, T. 8 N., R. 80 W., only about 1 mile southeast of the White River outcrop at the east margin of the map area.

Tweto (1957, p. 23–24) described various occurrences of rocks of Oligocene age in Middle Park, Colo., just south of North Park. Some of these rocks are probably correlative with the White River Formation of North Park.

MIOCENE SERIES

NORTH PARK FORMATION

Definition.—Geologists of the Army's 40th Parallel Survey first used the name North Park in their map atlas (King, 1876, map 1). The name North Park Tertiary was used in the volume on descriptive geology (Hague and Emmons, 1877, p. 127–129), and the name North Park Group was used in the volume on systematic geology (King, 1878, p. 431–434). In these works the name North Park was applied to all post-Cretaceous sedimentary rocks in North Park, and the age of the unit was tentatively designated as Pliocene. Thus the name North Park as used in the publications of the 40th Parallel Survey included at least a part of the Coalmont and the White River and North Park Formations as now recognized. Modern usage of the name North Park Formation began with Beekly's (1915, p. 66–71) restrictive redefinition of the name North Park Group.

Beekly (1915, p. 50–58, 66–67) recognized that the uppermost beds, consisting of shale and sandstone and intercalated beds of various volcanic materials, were different from the lower beds, which consist of dark-colored coal-bearing beds and lighter colored sandstone and conglomerate; he also noted that the two units were probably separated by an unconformity. In restricting the use of the name North Park to the upper beds, Beekly (1915, p. 66) stated:

In 1906 Veatch * * * used the name North Park to designate a * * * white calcareous and ashy formation in east-central Carbon County, Wyo., which, though considerably thicker is apparently the stratigraphic equivalent of the upper white beds of the North Park group of King. He used the name in a much more restricted sense in Wyoming than it was originally applied in North Park, for he made a distinction between the white ashy beds and the underlying formation or the lower part of the North Park group as defined by King. The name North Park is therefore restricted in this report to the topmost formation in North Park, which is characterized by white calcareous sandstone and ash beds.

Beekly (1915, p. 66, 68) designated the age of the North Park Formation as Tertiary, but he believed this formation to be younger than Eocene. He apparently considered the formation to be largely restricted to the central part of the North Park syncline, which extends roughly east-west along a narrow 20-mile strip across the central part of North Park, but he recognized correlative rocks in the low area northeast of Independence Mountain (Beekly, 1915, p. 67–68).

Beekly evidently included in his North Park Formation those beds now assigned to the White River Formation. Except for the exclusion of the White River Formation, Beekly's usage of the name North Park Formation is followed in this report. The North Park Formation is the youngest Tertiary formation in the area. It is probably late Miocene in age and unconformably overlie rocks as old as Precambrian and as young as Oligocene.

Thickness.—Inasmuch as the North Park Formation is not overlain by any younger formation, its original thickness is not known. Erosion has stripped the formation from much of the area. The maximum remaining thickness in the area is about 1,120 feet, in sec. 18, T. 8 N., R. 80 W. The maximum known remaining thickness elsewhere in North Park is about 1,800 feet on Owl Ridge, about 13 miles southeast of the area (Montagne and Barnes, 1957, p. 56).

Distribution and topographic expression.—The North Park Formation crops out in three separate areas in northwestern North Park. The first of these, which composes a part of the outcrop described by Beekly in redefining the North Park Formation, is Peterson Ridge in the southeastern part of the area. The second is the lowland northeast of Independence Mountain, in the northeast corner of the area. The third is in the vicinity of Pearl, in the northwestern part of the area.

Although composed mostly of rather easily eroded sandstone, the North Park Formation of Peterson Ridge is more resistant than the underlying Coalmont or White River Formations and forms a line of hills that stand 200 to 400 feet above the adjacent lowland. In the area northeast of Independence Mountain, the North Park Formation occupies an alluviated plain in a broad valley that extends from near the north edge of the area northwestward beyond Saratoga, Wyo. Near Pearl, it occupies part of a small isolated valley surrounded almost entirely by Precambrian highlands.

Relation to underlying rocks.—In all its outcrop areas the North Park Formation lies unconformably on the underlying rocks. Precambrian metamorphic rocks underlie the North Park in the area northeast of Independence Mountain and in the vicinity of Pearl, except for one small outcrop in sec. 7, T. 11 N., R. 80 W., where the North Park lies on the Chugwater Formation. Just north of the area, in Wyoming, about 2 miles northwest of Pearl, the North Park unconformably overlies older Tertiary rocks. In the Peterson Ridge area, the North Park truncates the White River and Coalmont Formations from east to west at a very low angle.

A small wedge of White River is present below the North Park on the north side of Peterson Ridge, but the White River is mostly covered and the nature of the White River-North Park contact is not known.

Lithology.—The North Park Formation consists mainly of calcareous ashy sandstone, conglomeratic sandstone, and limestone, and lesser amounts of shale, bentonitic clay, volcanic ash, and tuff. It is predominantly of fluvial origin and was deposited in shallow valleys by north-flowing streams.

The outcrops on Peterson Ridge are considered representative of North Park at the type area as interpreted from Beekly's (1915) redefinition. Most of the formation is calcareous ashy sandstone. Conglomerate and conglomeratic sandstone beds are fairly abundant particularly in the lower part of the formation (fig. 11). A few thin beds of claystone, limestone, tuff, and other rock types occur irregularly throughout the formation. The sandstone beds are mostly very fine to fine grained and are generally composed of quartz, detrital volcanic flow-rock fragments, volcanic glass, and minor amounts of feldspar, biotite, and other minerals. The cementing material is calcium carbonate or clay, or a mixture of the two. Calcium carbonate is the stronger cementing material; and in the lower part of the formation, highly calcareous sandstone or conglomerate, or sandy limestone form several prominent ledges. The cementing material in higher sandstone beds is predominantly clay, apparently composed of devitrified volcanic ash. This clay imparts to the beds a distinctive grayish-orange or tan color. The clay cement is rather weak, and the grayish-orange beds are relatively nonresistant. Gray beds are predominant in the lower one-quarter of the formation; grayish-orange beds are predominant in the upper three-quarters. Waterworn pebbles, cobbles, and boulders in the conglomerate and conglomeratic sandstone beds in the Peterson Ridge area are mostly volcanic flow rock;

but some, particularly in the lower part of the formation, are limestone and sandstone. The volcanic pebbles are of several varieties.

Most of the conglomerates are poorly sorted and are in lenticular bodies interpreted as stream-channel deposits. The limestones are sandy, and a few contain algal structures. A distinctive feature of many of the calcareous sandstone and limestone beds is abundant stemlike concretions. It is likely that the limestone beds were laid down in shallow lakes on an alluvial valley flat. In gross aspect the North Park Formation shows distinct even bedding, but individual units within the formation show variable bedding (fig. 11).

The North Park Formation in the area northeast of Independence Mountain is generally similar to that of the type area, but it shows the effect of greater distance from the source and is modified by an uneven content of metamorphic rocks of local origin. Most of the formation consists of calcareous ashy sandstone beds and fairly abundant beds of conglomerate and limestone, but all these rocks are generally finer grained than in the type area. The North Park Formation in this area occupies an ancient valley through which the ancestral North Platte River drained northward out of North Park. As first suggested by Montagne and Barnes (1957, p. 58), most of the material of the North Park Formation was derived from the south and southeast margins of North Park and was carried northward to the Independence Mountain area and Saratoga Valley by the ancestral

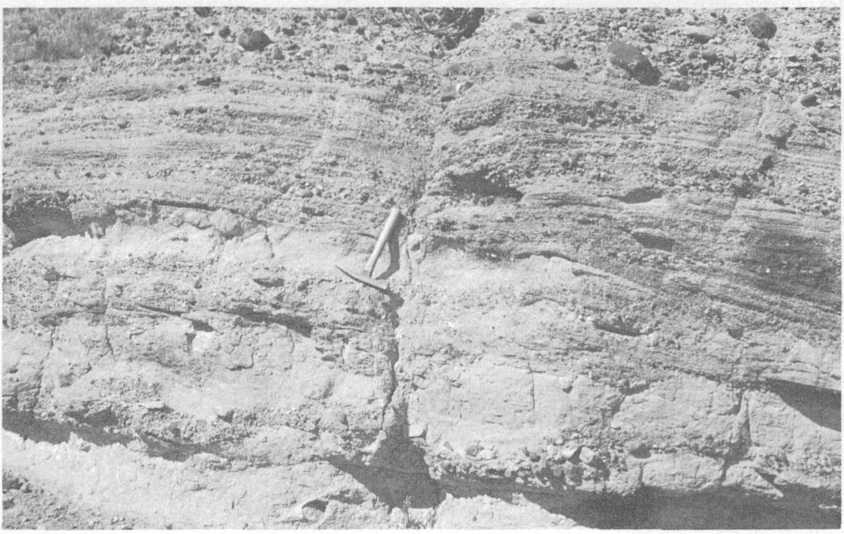

FIGURE 11.—Gravelly beds in the lower part of the North Park Formation at the west end of Peterson Ridge in the SW¼ sec. 11, T. 8 N., R. 81 W. Even-bedded conglomeratic sandstone above hammer; poorly bedded sparsely conglomeratic sandstone below hammer. Gravel constituents are predominantly waterworn volcanic flowrocks; matrix and sand constituents are ashy and highly calcareous.

North Platte River. Montagne and Barnes noted that the mean-size grade of the volcanic detritus increases southward from the north end of the Saratoga Valley to Independence Mountain. Pebbles in the conglomerate beds near Independence Mountain are considerably smaller in average size than those in the Peterson Ridge area 20 to 30 miles to the south.

The content of fragmental metamorphic rock in conglomerates of the North Park Formation in the Independence Mountain area increases markedly toward the local Precambrian outcrops, and the size of the fragments increases correspondingly. In the NE cor. sec. 7, T. 11 N., R. 80 W., the basal beds of the North Park Formation lie on Precambrian rocks and consist of as much as 200 feet of unsorted angular fragments of metamorphic rock which range in size from sand to boulders and are tightly cemented by calcium carbonate. Farther out in the valley, however, the metamorphic detritus generally does not exceed small-pebble size.

The North Park Formation is poorly exposed in the vicinity of Pearl; but the rocks appear to be mostly calcareous ashy sandstone beds, similar to the sandstone beds of the type area and of the area northeast of Independence Mountain. Conglomerate beds do not crop out south of the State line, in the Pearl area, but several crop out a mile or two north of the State line, in Wyoming. These conglomerates contain no volcanic pebbles but do contain angular fragments of Precambrian metamorphic rocks and rounded pebbles of limestone, siltstone, and sandstone.

The following partial composite stratigraphic section, measured on the north flank of Peterson Ridge, shows the lithology of the North Park Formation in the type area:

Partial composite section of the North Park Formation

[Upper 100 ft (approx.) measured in SE¼ sec. 18, T. 8 N., R. 80 W.; middle 980 ft (approx.) measured in NE¼ sec. 18, T. 8 N., R. 80 W.; lower 40 ft (approx.) measured in SW¼ sec. 7 and NW¼ sec. 18, T. 8 N., R. 80 W.]

North Park Formation (part):	*Feet*
Covered; slope wash and material from animal burrows is mostly grayish-orange fine-grained ashy sandstone; section measured to top of hill; stratigraphically higher beds absent	280
Sandstone, grayish-white, very fine to fine-grained, highly calcareous; contains abundant unaltered volcanic glass shards; alternating resistant and nonresistant beds; the more resistant beds are probably sandy limestone; thin bed of hard, white, opalized tuff about 4 ft below top of unit	27
Limestone, light-greenish-gray, sandy; contains abundant unaltered volcanic ash shards and quartz	6
Sandstone, grayish-white to light-grayish-orange, very fine to medium-grained, poorly sorted, noncalcareous to slightly calcareous, ashy; contains abundant detrital volcanic flow-rock fragments	20

Offset along the strike about 0.1 mile to the east

North Park Formation (part)—Continued	*Feet*
Limestone, light-gray, sandy; contains abundant quartz and fresh unaltered volcanic glass shards and minor devitrified volcanic glass; resistant, ledge forming	2
Sandstone, grayish-orange, very fine grained, calcareous, ashy	28
Limestone, light-brownish-gray; contains very abundant fresh unaltered volcanic ash shards; has spongy texture, obscurely even-bedded; hard, resistant at top and base; ledge forming	6
Sandstone, grayish-orange, very fine to fine-grained, slightly calcareous to highly calcareous, ashy; contains alternating resistant and nonresistant beds, but is mainly a nonresistant unit; the more resistant beds are highly calcareous; some beds contain stem-like lime concretions	148
Sandstone, grayish-orange, very fine to fine-grained calcareous to noncalcareous, ashy; contains a few thin resistant beds of sandy limestone; top of unit contains a thin bed of white opalized tuff	66
Tuff, white, noncalcareous; composed almost entirely of fresh unaltered volcanic glass and abundant shards; irregulary thin bedded, resistant, ledge forming	3
Sandstone, grayish-orange, very fine to fine-grained, slightly calcareous, ashy; contains sparse detrital volcanic flow-rock fragments	20
Poorly exposed to covered; surface wash and material from animal burrows is grayish-orange calcareous ashy sandstone; unit is mostly fine grained but has fairly abundant coarse grains; coarse grains are mostly quartz and detrital volcanic flow rock	156

Offset along the strike about 0.2 mile to the west

Poorly exposed; mostly light-brown to grayish-orange very fine to fine-grained slightly calcareous ashy sandstone	32
Conglomeratic sandstone, grayish-orange; sand matrix is fine to coarse grained, poorly sorted, highly calcareous, and ashy; contains abundant volcanic flow-rock detritus; pebble constituents are subrounded apparently waterworn dark volcanic flow-rocks, as much as 1½ in. long; most are ¾ to 1 in. long	6
Poorly exposed; mostly light-brown to grayish-orange fine-grained calcareous ashy sandstone	7
Conglomeratic sandstone, grayish-orange; sand matrix is fine to coarse grained, poorly sorted, highly calcareous, and ashy; contains abundant volcanic flow-rock detritus disseminated throughout unit; pebble constituents as much as about 1 in. in length are rounded, apparently waterworn, volcanic flow rocks	4
Sandstone, light-brown to grayish-orange, fine-grained, calcareous, ashy	11
Conglomerate; sand matrix is grayish orange, fine grained, calcareous, and ashy; pebbles as much as 1 in. long are dark, rounded, apparently waterworn, volcanic flow rocks; crossbedded	3
Poorly exposed; mostly sandstone like underlying bed	112
Sandstone, light-gray to grayish-orange, mostly fine- to medium-grained; many beds are fine to coarse grained, and poorly sorted; calcareous, ashy; contains abundant medium- to coarse-grained volcanic flow-rock detritus and sparse feldspar and dark minerals	55

North Park Formation (part)—Continued	*Feet*
Sandstone, light-gray to grayish-orange; mostly fine-grained, calcareous, ashy; abundant medium- to coarse-grained volcanic flow-rock detritus; sparse feldspar and dark minerals; moderately resistant, ledge forming	6
Sandstone, light-brownish-gray, fine-grained, noncalcareous to slightly calcareous, ashy; contains a little volcanic flow-rock detritus	24
Sandstone, light-brownish-gray, fine- to medium-grained, highly calcareous, ashy; contains very abundant volcanic flow-rock detritus and some feldspar and dark minerals	1
Limestone, grayish-orange; contains very abundant partly devitrified volcanic ash; nonresistant	3
Covered	8
Conglomeratic sandstone, light-greenish-gray, medium-gray-weathering, calcareous; sand matrix is fine to coarse grained, poorly sorted, and consists of quartz, detrital grains of volcanic flow rock, and some feldspar and dark minerals; pebble constituents are rounded, dark colored apparently waterworn volcanic flow rocks, as much as about 1 in. long; unit is resistant and ledge forming	3
Claystone, gray, noncalcareous	2
Conglomeratic sandstone, light-brown, calcareous; sand matrix is fine to medium grained; pebbles are less than 1/4 in. long and consist mostly of volcanic flow rock	6
Sandstone, light-gray to light-brownish-gray, fine-grained, calcareous to noncalcareous, ashy; highly calcareous resistant ledges at about 4, 15, 18, 21, and 25 ft above base	28
Conglomeratic sandstone, light-brownish-gray, highly calcareous; sand matrix is fine grained, ashy, has fairly abundant dark minerals, and contains sparse stemlike limy concretions; pebble constituents are most abundant in lower 1/2 ft, occur scattered elsewhere throughout unit; pebbles are light-colored rounded limestone and calcareous sandstone and dark volcanic flow rocks; largest pebbles as much as 1 in. long; resistant, ledge forming	3
Offset along the strike about 0.3 mile to the northwest	
Poorly exposed; mostly light-brown fine-grained slightly calcareous ashy sandstone; contains coarse detrital grains of volcanic flow rock	14
Sandstone, light-brownish-gray, fine- to coarse-grained, poorly sorted, noncalcareous, clayey; contains abundant detrital grains of volcanic flow rock and specks and stringers of white bentonite	9
Sandstone, light-brown, fine-grained, slightly calcareous; contains sparse specks and stringers of bentonite	11
Claystone, light-greenish-gray, noncalcareous, waxy-looking, white-speckled	1
Sandstone, light-brown, fine-grained, slightly calcareous; contains sparse coarse grains of quartz and volcanic flow rock	2
Sandstone, light-gray, fine- to coarse-grained, poorly sorted, highly calcareous; contains quartz, feldspar, glass, clay, sparse biotite, and sparse detrital volcanic flow-rock fragments	2

North Park Formation (part)—Continued	*Feet*
Claystone, light orange-brown, noncalcareous; contains sparse coarse to fine grains of quartz and biotite	2
Partial thickness, North Park Formation	1,117
Coalmont Formation (part):	
Sandstone, very light brown, fine- to medium-grained, poorly sorted; contains abundant coarse fragments; noncalcareous, main constituents quartz and feldspar, some mica, and clay; nonresistant	5
Poorly exposed; apparently conglomerate; pebbles are white and gray subangular quartz and feldspar as much as 3 in. long; contains fairly abundant biotite in surface wash; nonresistant	2
Siltstone, light-olive-brown, noncalcareous, clayey; contains fairly abundant fine- to medium-sized grains of quartz, feldspar, and mica	6
Sandstone, light olive-brown, very fine- to medium-grained, poorly sorted, slightly calcareous; constituents are mainly quartz and feldspar; has abundant biotite and other dark minerals; nonresistant	2+
Partial thickness, Coalmont Formation	15+

The following partial stratigraphic section, measured near the west end of Peterson Ridge, shows the lithology of the lower part of the North Park Formation in the type area:

Partial section of the North Park Formation in SW¼ sec. 12, T. 8 N., R. 81 W.

North Park Formation (part):	*Feet*
Sandstone, grayish-orange, very fine to medium-grained, poorly sorted, sparsely conglomeratic, highly calcareous, ashy; scattered pebbles as much as ½ in. long; larger grains and pebbles are detrital volcanic flow rock; much of the volcanic ash consists of unaltered shards; higher beds covered; top of measured section	35
Sandstone, light-gray, very fine to fine-grained, noncalcareous, ashy; contains sparse coarse grains of detrital volcanic flow rock	23
Conglomeratic sandstone, light-gray, matrix is fine to coarse grained poorly sorted calcareous ashy sandstone; larger grains are detrital volcanic flow rock; pebbles, mostly scattered but some in lenses, consist of subrounded volcanic flow rocks up to about 2 in. long; crossbedded, resistant, ledge forming	15
Sandstone, light-yellowish-gray, silty to very fine grained, calcareous, ashy	5
Conglomerate, light-gray, matrix is fine- to coarse-grained poorly sorted calcareous ashy sandstone; larger grains are detrital volcanic flow rock; pebbles are subrounded volcanic rock, mostly 1 to 2 in. long but as long as 7 in.; resistant, ledge forming	2
Limestone, light-yellowish-gray, algal; contains fairly abundant fine to coarse detrital grains of volcanic flow rock	7
Conglomeratic sandstone, light-gray; matrix is fine- to coarse-grained poorly sorted calcareous ashy sandstone; larger grains are detrital volcanic flow rock; pebbles occur in lenses and consist of subrounded volcanic flow rock, as much as about 1 in. long	3

North Park Formation (part)—Continued	*Feet*
Bentonitic shale, light-brown; weathers mottled light green and reddish brown; fissile	7
Sandstone, light-yellowish-gray, very fine to fine-grained, calcareous, ashy; contains sparse detrital fragments of volcanic flow rock	3
Bentonitic shale, light-brown; weathers mottled light green and reddish brown; fissile	5
Sandstone, gray, fine- to medium-grained, poorly sorted, calcareous, ashy; coarser constituents are detrital fragments of volcanic flow rock	1
Sandstone, light-yellowish-gray, very fine to fine-grained, calcareous, ashy; contains sparse dark minerals and rock fragments	8
Conglomeratic sandstone, light- to medium-gray; matrix is coarse to very coarse detrital volcanic flow-rock fragments in very fine grained highly calcareous ashy sandstone; pebbles, in lenses and scattered, consist of subrounded volcanic flow rock as much as about 4 inches long; crossbedded	4
Sandstone, light-brownish-gray, fine-grained, noncalcareous; contains fairly abundant coarse detrital grains of volcanic flow rock	3
Conglomerate, light-gray; matrix is fine- to coarse-grained calcareous ashy sandstone; pebbles are subrounded volcanic flow rocks as much as about 4 in. long	1
Sandstone, light-brownish-gray, fine-grained, noncalcareous; contains fairly abundant coarse detrital grains of volcanic flow rock	13
Conglomerate, light-gray; matrix is fine- to coarse-grained calcareous ashy sandstone; pebbles are subrounded volcanic flow rocks as much as about 6 in. long	1
Sandstone, light-gray, fine-grained, calcareous, ashy; contains sparse coarse- to pebble-sized fragments of volcanic flow rocks; crossbedded	4
Conglomeratic sandstone, light- to medium-gray; matrix consists of coarse to very coarse detrital grains of volcanic flow rock in very fine grained highly calcareous ashy sandstone; pebbles, mostly scattered but some in lenses, consist of subrounded volcanic flow rock ranging from about ½ to 6 in. long; crossbedded	12
Sandstone, light-gray, fine-grained, noncalcareous, ashy; contains abundant fine to coarse fragments of detrital volcanic flow rock	17
Sandstone, light-gray, very fine grained, highly calcareous, ashy; contains sparse coarse detrital volcanic flow-rock fragments; resistant, ledge forming	2
Sandstone, light-brownish-gray, light-gray weathering; fine-grained, noncalcareous, ashy; contains fairly abundant coarse detrital grains of volcanic flow rock	13
Conglomeratic limestone, light-gray; matrix is calcium carbonate; detrital fragments range from fine sand to pebbles, as much as about ½ in. long; consist of quartz, feldspar, volcanic flow rock, hornblende, and biotite; largest pebbles are quartz and feldspar; resistant, ledge forming	2
Sandstone, light-gray, very fine grained, calcareous ashy	5
Limestone, light-gray, sandy; contains abundant very fine grained volcanic glass, quartz, and feldspar; resistant, ledge forming	6
Sandstone, light-gray, fine grained, calcareous, ashy	7

North Park Formation (part)—Continued	*Feet*
Limestone, light-gray; brown weathering near top; sandy; contains abundant very fine grained volcanic glass, quartz, and feldspar; contains stemlike lime concretions; resistant, ledge forming	5
Sandstone, light-brown to light-grayish-brown, very fine grained, calcareous, ashy	13
Limestone, light-brownish-gray, sandy; contains very abundant very fine grained volcanic glass, stemlike limy concretions, quartz, and feldspar; resistant, ledge forming	3
Sandstone, light-greenish-gray, very fine grained, calcareous, ashy	12
Limestone, light-brownish-gray, sandy; contains abundant very fine grained volcanic glass, quartz, and feldspar; resistant, ledge forming	1
Sandstone, light-greenish-gray, very fine grained, highly calcareous, ashy	11
Limestone, light-gray, sandy; contains abundant very fine to fine grained quartz and volcanic glass shards; resistant, ledge forming	2
Sandstone, light-brown and light-greenish-gray, fine grained, highly calcareous, ashy	10
Limestone, light-gray, sandy; contains abundant very fine to fine grained quartz and volcanic ash shards; contains stemlike limy concretions and algal-like markings; even bedded; weathers to small blocks, resistant, ledge forming	4
Poorly exposed; mostly medium- to light-gray highly calcareous conglomeratic sandstone; matrix is calcium carbonate; detrital fragments range from fine sand to pebbles as much as ½ in. long and consists of quartz, feldspar, volcanic flow rock, hornblende, and biotite; largest pebbles are quartz and feldspar and occur about 17 ft above base of unit; unit probably contains some sandy limestone beds	32
Sandstone, light-brown, medium grained, slightly calcareous, ashy	1
Tuff, light-brownish-gray; consists of fine to coarse grains of quartz, volcanic flow-rock fragments, biotite, and sparse feldspar in a matrix of devitrified volcanic glass, now mostly bentonitic clay; quartz occurs in clear stubby doubly terminated crystals	6
Bentonite, very light gray; contains sparse but conspicuous biotite	4
Sandstone, light-brown, fine- to medium grained, slightly calcareous, ashy	3
Limestone, light-brownish-gray; contains sparse silt to fine sand composed of volcanic ash, quartz, and detrital volcanic flow rock; resistant, ledge forming	1
Sandstone, gray, very fine grained, calcareous, ashy	4
Limestone, light-gray; contains sparse to abundant particles ranging from silt to fine sand composed of volcanic ash, quartz, and detrital volcanic flow rock; resistant, ledge forming	2
Sandstone, light-brownish-gray, fine- to medium-grained, poorly sorted, slightly calcareous, ashy	6
Covered; base taken at alluvium of North Platte River, probably not more than 30 ft above North Park-Coalmont contact	81
Total measured thickness	405

Correlation and age.—Beekly (1915, p. 68–69) correlated the North Park Formation in its type area with the strata that lie northeast of Independence Mountain and extend northwestward into the Saratoga Valley, Wyo. A similar correlation has been made by McGrew (1951, p. 56; 1953, p. 64), Knight (1953, p. 76), Steven (1956, p. 43–44), Montagne (1957, p. 39), and Montagne and Barnes (1957, p. 55).

Many fossil vertebrates have been found in the North Park Formation and other Tertiary units in the Saratoga Valley area by Ashley (1948), McGrew (1951, p. 57), and Montagne (Montagne and Barnes, 1957, p. 59). Montagne and Barnes (1957, p. 59) summarized the results of the fossil discoveries and concluded that the greater part of the North Park Formation in the Saratoga Valley area is late Miocene in age. They reported fossil collections of late Miocene vertebrates from two localities in the upper Saratoga Valley. A locality in the NW¼ sec. 8, T. 11 N., R. 80 W., Jackson County, Colo., yielded *Ustatochoerus* sp., *Merycodus* (?) sp., and *Eucastor sp.* A locality in the SW¼ sec. 7, T. 12 N., R. 80 W., Carbon County, Wyo., yielded *Merychippus* sp. similar to *M. republicans*, a camel similar to *Pliauchenia* sp., and *Merycodus.*

Fragments of vertebrate fossils of probable late Miocene age were found in the North Park Formation in the type area on Peterson Ridge (Hail and Lewis, 1960). These fossils permit tentative dating of the North Park in the type area and support correlation with the rocks northeast of Independence Mountain and in Saratoga Valley. At locality D437 on Peterson Ridge, two weathered fragments of a fossil horse tooth were found in a bed of light-gray calcareous sandstone about 800 feet above the base of the formation. Late Miocene vertebrate fossils were also collected from two localities (D416, D272) in the area northeast of Independence Mountain, probably near the fossil localities discussed by Montagne and Barnes (1957, p. 59). At locality D416, fragments of fossil horse teeth were found in beds of light-brown fine-grained calcareous sandstone that are estimated to be several hundred feet above the base of the formation. At locality D272, fragments of an oreodont jaw containing several teeth were found in a bed of light-gray fine-grained calcareous sandstone 200 to 300 feet above the base of the formation. Tentative identification of the specimens by G. E. Lewis of the U.S. Geological Survey, and the localities from which they came are as follows:

Merychippus sp.; USGS fossil vertebrate loc. D437, NW¼SW¼ sec. 17, T. 8 N., R. 80 W., Jackson County, Colo.: Two fragments of an upper cheek tooth.

Merychippus sp.; USGS fossil vertebrate loc. D416, SW¼ sec. 7, T. 12 N., R. 80 W., Carbon County, Wyo.: Four fragments of upper cheek teeth.

?*Brachycrus* sp.; USGS fossil vertebrate loc. D272, NE¼ NE¼ sec. 7, T. 11 N., R. 80 W., Jackson County, Colo.: Fragment of right ramus with one incomplete lower molar and fragment of left ramus with lower molar and incomplete lower molars 1 and 3.

G. E. Lewis (Hail and Lewis, 1960, p. B260) made the following comment:

These identified forms are elements of a fauna, probably of late Miocene age, comparable to the fauna in the upper part of the Hemingford group of Nebraska which Lugn (1939, p. 1253–1258, 1264, table 2) believes to be of latest Miocene age. Many authorities believe that this fauna may be as old as early late Miocene, somewhat older than Lugn believed it to be (Wood and others, 1941, pl. 1).

A locality in Wyoming about 3 miles northwest of Pearl has yielded vertebrate fossils classed as "Hemingfordian" (middle Miocene) by Montagne and Barnes (1957, p. 59), who refer all the Tertiary beds in the Pearl area to the Browns Park Formation. The beds that yielded the fossils differ lithologically from those of the North Park Formation elsewhere. They are massive sandstone and show none of the bedding typical of the North Park. These beds are calcareous only in the more resistant and well-cemented lenses, in contrast to the usually highly calcareous rock of the North Park. They are drab brown in contrast to the lighter gray, brown, and grayish-orange colors of the North Park. Finally, the beds underlie, and contrast sharply in lithology with, a well-bedded sequence of conglomerate, sandstone, and limestone of typical North Park appearance. Apparently two formations are present—the North Park Formation and an underlying middle Miocene unit called Browns Park by Montagne and Barnes; they are probably separated by an unconformity. None of the beds of the lower unit are present south of the State line within the mapped area, and therefore all the Tertiary rocks shown on the map in the Pearl area are referred to the North Park Formation.

Vine and Prichard (1959, p. 207–212) have applied the name North Park(?) Formation to Tertiary rocks in the Miller Hill area of southern Wyoming, about 35 miles northwest of Pearl, and in the absence of fossils, classed them as Pliocene(?) in age.

PLIOCENE(?) SERIES

LOCAL BOULDER CONGLOMERATE

A thick deposit of locally derived boulder conglomerate covers an area of several square miles on the highest part of Independence Mountain and extends down adjacent slopes near the head of Parsons Draw to an altitude of about 8,500 feet. Walters (1957, p. 87, map) called the boulder conglomerate the High Level Conglomerate, and mapped outcrops on Independence Mountain as far east as the North Platte River, about 2 miles east of the area.

The conglomerate is largely unsorted fragments of Precambrian metamorphic rock ranging in size from sand to very large boulders. On slopes underlain by it, boulders of various size are strewn over the surface as on glacial till. The largest boulders are 12 feet long, but most of them are smaller, generally ranging from 2 to 4 feet. Many of the boulders are rounded, but the rounding is probably due more to weathering than to abrasion. About half the deposit is pebble sized or larger; the rest is mainly coarse sand. Many boulders seen in the better exposures are highly weathered and disintegrate readily, and presumably much of the sand in the unit is derived from the weathering and disintegration of larger fragments. All the constituent material is from Precambrian metamorphic rocks; sedimentary and volcanic constituents seem to be absent.

Much surface wash from the conglomerate is found downslope from the main body of the conglomerate, and the contact with underlying bedrock is obscure. It is particularly difficult to distinguish some of the sandy beds of the boulder conglomerate from some of the sandy beds of the Coalmont Formation inasmuch as both are composed of material derived from Precambrian crystalline rocks; however, the Coalmont in the Independence Mountain area contains no boulders except in the basal conglomerate in which they generally do not exceed 1 foot in length.

The boulder conglomerate is chiefly a talus or piedmont-fan deposit and, as first suggested by Walters (1957), was probably derived from an upfaulted segment of the Independence Mountain thrust plate. Independence Mountain is composed mostly of Precambrian metamorphic rocks in a locally imbricate thrust-fault zone extending northwestward across much of the northern part of the area. Parts of two or more of the upper imbricate thrust-fault plates were destroyed by erosion, and the resulting debris formed the boulder conglomerate.

Although precise dating of the deposit is not possible, the author believes the Independence Mountain thrust fault and associated imbricate and high-angle faults that cut the thrust plate and were responsible for the deposit to be post-Laramide structural features, probably Pliocene or late Miocene in age. The deposit, therefore, is here designated Pliocene(?).

QUATERNARY SYSTEM

PLEISTOCENE SERIES

Pleistocene deposits in northwestern North Park include till of three glaciations, outwash and terrace gravels, and alluvial-fan and pediment gravels. Outwash and glaciofluvial terrace gravels of the two younger Pleistocene glaciations are clearly correlative with till of mountain valley moraines. Older terrace gravels may in part be of glaciofluvial origin, but they cannot be definitely correlated with older glacial till deposits. The pediment and alluvial-fan gravels are probably not genetically related to glaciation.

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, of probable pre-Bull Lake age, includes only till; terrace gravels possibly of the same age but of questionable glacial origin are designated simply "older gravels." Drift of glaciations 2 and 3, of probable Bull Lake and Pinedale ages, respectively, includes till, outwash, and glaciofluvial terrace gravel.

Table 12 shows suggested correlations of glacial deposits in northwestern North Park with glacial deposits elsewhere in northern Colorado. The correlations are based on comparison of physiographic, stratigraphic, and weathering characteristics.

DRIFT OF GLACIATION 1

Glacial till of probable pre-Bull Lake age caps an interstream upland south of the Rainbow Lakes in the extreme southwest corner of the area. The till rests in part on an old erosion surface of relatively gentle relief cut on Precambrian rocks and occupying the summit of a divide between the Rainbow Lakes and Agua Fria Lake, just west of the area. The erosion surface is bounded in part by precipitous cliffs as much as 800 to 1,000 feet high along valleys deepened by younger glaciers. Till of glaciation 1 also crops out near the headwaters of Hell Creek in T. 9 N., R. 82 W., where it mantles part of an upland valley that apparently was not occupied by younger glaciers. A heavy brown soil that covers a broad upland valley north of Bear Mountain at the west-central margin of the area may in part be weathered till of glaciation 1, but no conclusive evidence supports the correlation.

Till of glaciation 1 is a relatively thin sheet that has no morainal form. Irregularities in the topography of the till sheet may be due to concentrations of the better preserved boulders, or may reflect irregularities in the underlying topography. The till supports a very heavy forest of conifers and is nowhere seen in fresh exposures; its nature is known only from material at the surface. In the Rainbow Lakes area this surface material is composed entirely of quartz monzonite in boulders or smaller fragments as small as sand. Most of the boulders do not exceed 5 feet in length but a few reach 12 feet. All the boulders are rounded by weathering except where broken in place by weathering along joints or other planes of weakness. Some boulders are spheroidally weathered, and many are so weathered

TABLE 1.—*Suggested correlation of glacial deposits, northern Colorado mountains*

	Rocky Mountain National Park, Colo. (after Richmond, 1960)		Poudre Valley, Colo. (Ray, 1940)	Michigan River Basin, North Park, Colo. (Eschman, 1955)		East flank of Park Range North Park, Colo. (this report)		Park Range Colo. (Atwood, 1937)
			Till	Till	Glaciofluvial surfaces	Till	Outwash and terrace gravels	Till
Recent	Neoglaciation	Historic stade	Sprague (Wisconsin V)	Cirque moraines, protalus ramparts, and rock streams		Cirque deposits	None	
		Temple Lake stade						
Pleistocene	Pinedale glaciation	Late stade	Long Draw (Wisconsin IV)	American Lakes	Terraces 4–7 feet above present stream	Drift of glaciation 3	Drift of glaciation 3	Wisconsin (moraine deposits)
		Middle stade	Corral Creek (Wisconsin III)	Silver Creek	4H surface			
		Early stade						
	Bull Lake glaciation	Late stade	Home (Wisconsin II)	Gould	Walden surface	Drift of glaciation 2	Drift of glaciation 2	Pre-Wisconsin (moraine deposits)
		Early stade	Twin Lakes (Wisconsin I)					
	Pre-Bull Lake glaciation		Prairie Divide	Owl Mountain	"Higher surface" (glacial origin questionable)	Drift of glaciation 1	Older terrace gravels (glacial origin questionable)	Pre-Wisconsin (possible precanyon drift)

that they disintegrate easily from a hammer blow. Part of the sand-sized material in the till probably resulted from the disintegration of boulders. Just west of the mapped area, a single exposure shows that the rocks under the till of glaciation 1 are thoroughly weathered quartz monzonite.

Near the south rim of the canyon at Rainbow Lakes, till of glaciation 1 is overlain by a well-defined lateral-moraine ridge of glaciation 3. The contrast in physiographic form between the two tills is conspicuous.

Richmond (1957) summarized information on pre-Wisconsin glaciation in many parts of the Rocky Mountain region and later substituted the term pre-Bull Lake for pre-Wisconsin (Richmond, 1962). Concerning physiographic habit, he (1957, p. 240) stated:

> Deposits of pre-Wisconsin till tend to be sheetlike in form and to lack morainal topography, though vestiges of moraines or kettles have been noted locally * * * In most areas the deposits cap high interstream divides or remnants of broad-valley erosion surfaces along the upper slopes of canyons and lie above or beyond the outer limits of younger tills * * *. Some cover extensive upland areas * * * but most have a patchy distribution * * * This physiographic setting has suggested to many writers that the pre-Wisconsin till is precanyon in origin. The deposits tend to be dissected from 200 to over 1,000 feet by modern trunk streams and to a lesser extent by an orderly tributary drainage.

Richmond (1957, p. 249) pointed out that boulders on the surface of the till are considerably more weathered than boulders on younger tills and that disintegrated, "rotted," or crumbly boulders are reported by many writers to be abundant in the till, especially in deposits containing crystalline rocks. The till of glaciation 1 in northwestern North Park is comparable in physiographic habit and degree of weathering of surface boulders to the pre-Wisconsin (pre-Bull Lake) glacial deposits as described by Richmond and is therefore tentatively correlated with them in this report.

OLDER TERRACE GRAVELS

Of five generally distinct terrace levels recognizable throughout the area, the upper three are rock-cut stream terraces mantled by thin deposits of weathered gravel, and the lower two are glaciofluvial and correlative with glaciations 2 and 3. The three older terraces and gravels predate the drift of glaciation 2 and are therefore of probable pre-Bull Lake age. Determination of the relative age of the gravels is based mainly on the relative topographic position of the terraces on which they lie. Generally the lowest of the three older terrace levels lies 20 to 30 feet above the terrace correlated with glaciation 2; the next is 10 to 50 feet higher; and the highest is 10 to 40 feet above the middle one. Locally, sublevels of the terraces are present, and distinction between the main levels is difficult.

All three of the older terrace gravels are similar in lithology and consist of stream-laid material ranging in size from sand to boulders as much as 14 inches in length. The gravels generally possess a fair degree of bedding and sorting, although these characteristics may be obscure locally. The pebbles and boulders in the gravel are subangular to well rounded; but the sand fraction is mostly angular. The gravels are unevenly cemented by calcium carbonate, limonite, or clay; so, in most places they are fairly coherent and resistant. They were almost entirely derived from Precambrian crystalline rocks but contain a small fraction of resistant sedimentary rocks, notably sandstone of the Dakota. Pink to gray granitic rock predominates among the Precambrian crystalline constituents, but north of Hell Creek dark metamorphic rock composes as much as 40 percent of the gravel. In the extreme southeastern part of the area, the youngest of the three older gravels contains sparse pebbles of volcanic flow-rock.

The relative antiquity of the older terrace gravels is demonstrated by the amount of weathering that has affected them. About 1 mile south of Raspberry Creek, in sec. 18 and 19, T. 8 N., R. 81 W., a well-developed but discontinuous soil or weathering zone as much as 5 feet thick bevels across the oldest and middle terrace gravels as well as an outcrop of interterrace bedrock. The lower part of the weathered zone (C horizon) commonly contains abundant powdery calcium carbonate; the upper part (B horizon) is jointed blocky noncalcareous clay, generally capped with dark-brown loamy sand (A horizon). Where a well-developed soil is not present, a calcium carbonate or caliche zone appears to underlie the dark-brown surface layer. Many pebbles in the gravel are so weathered that they disintegrate readily. Dark metamorphic rocks rich in biotite and hornblende apparently weather much more readily than quartz- and feldspar-rich granitic rocks, and the proportion of decomposed gravel is usually greater where the proportion of dark metamorphic rock is greater. The surfaces of the various older terrace gravels commonly are strewn with a residual concentration of iron-stained quartz or quartzite, the most resistant rocks in the gravels.

The maximum measured thickness of the oldest of three older terrace gravels is about 12 feet; of the intermediate gravel, about 14 feet; and of the youngest gravel, about 17 feet.

At various places in the area between Hell Creek and Roaring Fork near the outer margins of glacial moraines, outwash fan gravel of glaciation 2 unconformably overlies the two lower and possibly all three of the older terrace gravels; till of glaciation 2 may also unconformably overlie the older gravels at those places.

The three older terrace gravels may be glaciofluvial outwash gravels of pre-Bull Lake glaciations, but this correlation has not been proved. None of the gravels can be traced into deposits of till. The fabric and lithology of the older terrace gravels are, however, indistinguishable from those of the younger terrace gravels that are definitely correlative with the tills of glaciations 2 and 3.

DRIFT OF GLACIATION 2

Drift of glaciation 2 of probable Bull Lake age includes deposits of till, outwash, and glaciofluvial terrace gravels. Locally, this drift unconformably overlies older Pleistocene terrace gravels and is unconformably overlain by till of glaciation 3.

Glaciers of glaciations 2 and 3 were approximately coextensive. They were mainly confined to stream valleys on the east flank of the Park Range but extended to the basin floor at many places and coalesced in their terminal parts. Considerable areas of the drift of glaciation 2 were doubtless either destroyed by younger glaciers or covered by their deposits. Exposures of drift of glaciation 2 are scattered intermittently along almost the entire east flank of the Park Range and are generally marginal to moraines of glaciation 3. Outwash fans of glaciation 2 occupy fairly extensive areas adjacent to the moraines, and glaciofluvial terrace gravels extend many miles beyond the outwash fans into the basin along the North Platte valley beyond the eastern margin of the area.

Moraines of glaciation 2 have a subdued topography resulting from a lengthy period of postglacial weathering and erosion (fig. 12): bouldery hummocks are present but inconspicuous; relict undrained depressions are in large part filled; lakes and swamps are scarce; the surface contains only a moderate scattering of weathered boulders; and terminal ridges are inconspicuous and considerably trenched by postglacial streams or are absent.

Till typical of the drift of glaciation 2 throughout the mapped area is exposed in the terminal moraine of Newcomb Creek, 2 miles south of the mapped area. There, in SE¼ sec. 11, T. 7 N., R. 82 W., about 6 feet of the till is exposed in an irrigation ditch. Its matrix is noncalcareous coarse sand, derived in part from decomposed granitic rock; it is light brown to grayish orange, possibly owing to limonite staining. The till is moderately well cemented by limonite and fairly abundant clay that is probably derived from weathering of feldspar and mica. Bedding and sorting are apparently absent. Pebbles, cobbles, and boulders are abundant; the boulders reach a maximum length of 6 feet. The boulders are predominantly very coarse grained quartz monzonite, typical of that in the adjacent Park Range. One-

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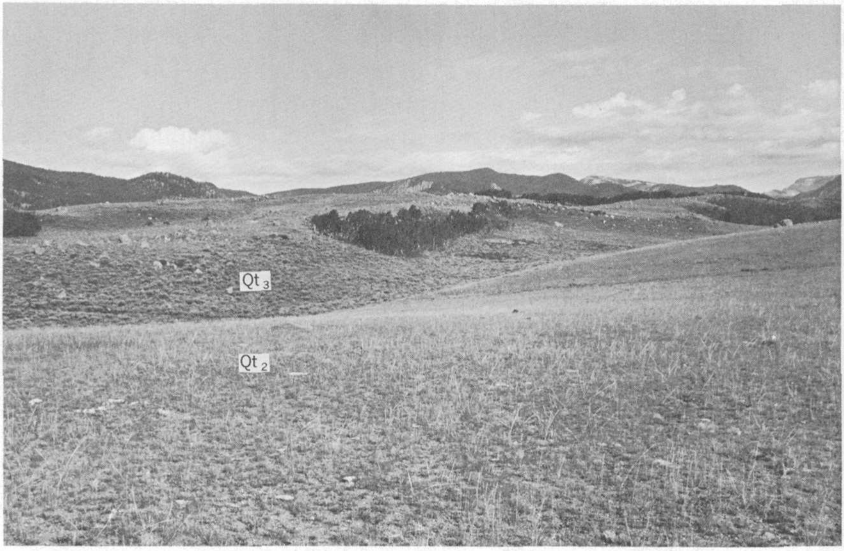

FIGURE 12.—Terminal moraine surfaces of glaciation 2 (Qt_2) in the foreground and glaciation 3 (Qt_3) in the background, in the W½ sec. 1, T. 8 N., R. 82 W. Smooth, subdued, nonbouldery surface is typical of the older, more weathered till of glaciation 2. Irregular, hummocky, bouldery surface is typical of the younger, less weathered till of glaciation 3.

third to one-half the cobbles and boulders are thoroughly decomposed or in an advanced stage of decomposition. Fresh boulders are pink to pale red; decomposed boulders are brown or yellowish gray. The till at this locality is not covered by a well-developed soil, but is capped by about one foot of brownish-gray noncacareous, well-compacted loamy sand (A horizon).

The topography of the moraine surface in this area is irregular but relatively gentle. A few swampy depressions are present, but the surface is generally well drained. Boulders as much as 8 feet in length lie on the surface; these boulders are well rounded by weathering except for those that are parted along joints. Much of the moraine surface here is composed of sand apparently derived from the weathering of larger fragments, and the modification of the originally more hummocky morainal topography probably is mainly due to the weathering and disintegration of the morainal material.

Outwash gravels of glaciation 2 are found in fans marginal to moraines and on stream terraces. In most places, the outwash and terrace gravels of glaciation 2, as well as underlying bedrock, were dissected before glaciation 3, so that the gravels are generally perched higher than gravels of the younger glaciation.

Gravels of the fans resemble those of the terraces except that the boulders increase abruptly in size within a few hundred feet of the outer margins of the moraines, so that the gravel resembles till. Generally, however, the outwash gravels are typical alluvial gravels (fig. 13); bedding is generally indistinct except in sand lenses, and sorting is poor. The matrix is usually coarse sand; the gravel constituents usually range in size from small pebbles to boulders as much as 10 inches long. Most of the gravel is at least somewhat rounded and much of it is well rounded. Most of the material is Precambrian granitic and metamorphic rock, but a minor amount is hard sandstone of the Dakota. In the extreme southeastern part of the area, where Little Grizzly and Big Grizzly Creeks join to form the North Platte River, terrace gravels of glaciation 2 are composed largely of volcanic flow rock. This evidence suggests a source area in the Rabbit Ears Range at the south margin of North Park. Weathering of the gravel is conspicuous in many outcrops. Many of the cobbles and boulders are thoroughly decomposed, especially where hornblende- or biotite-rich metamorphic rocks predominate. A well-developed soil zone does not appear to be present on the gravel, although a calcium carbonate or caliche zone (C? horizon) is present in the upper 1 to 3 feet, and the gravel is commonly overlain by dark-brown loamy sand (A horizon). Clay or calcium carbonate weakly cements the gravel to a fair degree of coherence in most places.

The terrace gravels lie a few feet to about 30 feet above adjacent terrace gravels of glaciation 3 and thus indicate the amount of inter-

FIGURE 13.—Glaciofluvial terrace gravel of glaciation 2, exposed in a gravel pit in the SW¼ sec. 19, T. 9 N., R. 80 W. Waterworn stream-laid outwash gravel consists almost entirely of Precambrian crystalline rocks.

glacial erosion. In some places bedrock is not exposed in the terrace slopes, indicating either that the interglacial erosion did not cut entirely through the gravels of glaciation 2, or that valley-fill gravel of glaciation 3 was thick enough to cover the bedrock in terrace slopes.

Suggested correlation of the drift of glaciation 2 with various glacial deposits elsewhere in northern Colorado is shown in table 1. Richmond (1960, p. 1373–1374) correlated certain moraines of Rocky Mountain National Park, Colo., with moraines of the Bull Lake Glaciation in Wyoming, by use of the following criteria: The Bull Lake and equivalent moraines are the oldest and most extensive of those having well-preserved morainal topography; they have mature slopes that are less bouldery than those of the Pinedale Glaciation; the slopes are breached by streams; the tills are compact, stained brown, and contain the same general proportion of deeply weathered stones; and the soils have similar mature zonal profiles and are less weathered than those on the pre-Bull Lake tills, but are more strongly developed than those on tills of the Pinedale Glaciation. Except for the apparent lack of mature soil profiles, Richmond's criteria for correlation with deposits of the Bull Lake Glaciation in the Wind River Mountains, Wyo., generally apply to moraines of glaciation 2 of western North Park.

DRIFT OF GLACIATION 3

Most of the visible glacial deposits in western North Park are a product of glaciation 3. The drift of this glaciation includes till, outwash, and glaciofluvial terrace gravels. It locally unconformably overlies drift of glaciation 2 and locally is unconformably overlain by Recent glacial and alluvial deposits. At least two and possibly three topographically distinct moraines are recognizable locally within the drift of glaciation 3; these probably indicate two or three advances of the ice during the glaciation. The deposits were not separately mapped.

Till of glaciation 3 is found in moraines occupying most of the valleys cutting the east flank of the Park Range and in large coalescing terminal moraines extending outward onto the basin floor. In the area between Hill Creek and the south end of Bear Mountain, the lower slopes of the Park Range are largely covered by widespread drift of glaciation 3 spread in a morainal apron from the mountain front to the basin floor. Some of the surficial material in this area is of questionable glacial origin and doubtless includes landslide, talus, and other colluvial material. Extensive outwash fans and valley trains adjoin most of the terminal moraines, and glaciofluvial terrace gravels extend many miles out into the basin. Confined within the terminal and lateral walls of many of the larger moraines are parklike areas of little relief which contain lake, swamp, and alluvial deposits including some outwash. These deposits are included on the geologic maps (pls. 1, 2, 3) with till of glaciation 3. Valleys containing such deposits include the Big Creek Lakes area, parts of Bear Creek valley, Lone Pine Creek valley, Roaring Fork valley, and Norris Creek valley (Livingston Park).

The youthful, disordered topography of the moraines, especially the terminal moraines, is the most distinctive feature of the drift of glaciation 3 (fig. 12) and is easily distinguished from moraines of glaciation 2, which have a more subdued topography. Bouldery hummocks are abundant; numerous large fresh boulders litter the surface. Abundant undrained depressions contain lakes and swamps. Terminal and lateral ridges are sharp and well defined, and some lateral ridges stand as much as 500 feet above adjacent valley floors. Across terminal loops of the larger valley moraines, trenching generally is poorly established even by major streams. The moraines commonly support a heavy forest growth.

Many of the outwash fans, particularly in the broad valley west of Sheep Mountain, contain relict marks of radial drainage lines; otherwise the fans and glaciofluvial terrace gravels of glaciation 3 are little different topographically from the gravels of glaciation 2. There has been very little trenching of the outwash or terrace gravels since glaciation 3. In some places Recent alluvium overlies the outwash and terrace gravels with no apparent topographic break. The maximum amount of postglacial cutting took place mainly in downstream areas several miles from the margins of the terminal moraines. There, where terrace gravels of glaciation 3 form the floor of an abandoned course of the North Platte River and the North Fork, the maximum postglacial cutting probably does not exceed 10 feet.

Till typical of the drift of glaciation 3 is exposed in the terminal moraine in sec. 18 and 19, T. 9 N., R. 81 W., about three-fourths of a mile northwest of the Carlstrom Brothers ranch. As much as 14 feet of till is exposed in a cut along an irrigation ditch in the NE¼ sec. 19, T. 9 N., R. 81 W. (fig. 14), and as much as 16 feet of till is exposed in a roadcut in the SE¼ sec. 18, T. 9 N., R. 81 W. At these localities the matrix makes up about two-thirds of the till and consists of clayey, medium to coarse sand. It is noncalcareous at these localities, but tills in local exposures elsewhere are calcareous. The larger constituents of the till range from small pebbles to boulders as much as 4 feet in length. No bedding or sorting is apparent. The till is grayish brown to light brown, and it weathers light brown. It is moderately coherent. The constituent material is almost entirely Precambrian granitic or metamorphic rock derived from the nearby

FIGURE 14.—Till of glaciation 3 near Lone Pine Creek in the NE¼ sec. 19, T. 9 N., R. 81 W.

Park Range. The degree of decomposition by weathering of the gravel constituents is variable; in the irrigation-ditch exposure probably no more than 5 percent of the gravel is decomposed, whereas in the roadcut exposure, as much as one-third of it is decomposed. The till of glaciation 3 here and elsewhere is assumed to contain a considerable amount of reworked drift of glaciation 2 which had once filled the valleys, and thus includes material that may have been weathered both before and after deposition of the drift of glaciation 2. In general, the till of glaciation 3 contains far fewer decomposed fragments than the till of glaciation 2. A well-developed soil is not present on the till, but the till is capped by an A soil horizon which consists of a few inches of dark sandy loam.

The surface of the moraine of glaciation 3 is littered with large boulders, some as much as 30 feet in length. All the boulders and almost all the surface gravel consist of coarse-grained Precambrian granitic or metamorphic rocks. Weathering of the boulders is slight, except along joints; some boulders have been parted in place along the weathered joints. A few boulders show moderate spheroidal weathering, but on some, a light red stain is the only sign of weathering. This fresh appearance is in sharp contrast to weathered boulders on terminal moraines of glaciation 2.

Good exposures of outwash fan and terrace gravels of glaciation 3 are sparse owing to the lack of postglacial stream trenching, but the gravels appear to be lithologically similar in most respects to the outwash gravels of glaciation 2. Bedding is obscure and sorting is poor. Where seen, the gravel constituents range from small pebbles to cobbles as much as 6 inches in length. Presumably, the gravel size increases in the outwash fans near the margins of the moraines. All of the larger fragments show some rounding and most are subrounded. The gravel consists almost entirely of Precambrian crystalline rocks, although locally in the North Platte valley as much as 10 percent is small pebbles of volcanic flowrock. The matrix is poorly consolidated noncalcareous sand, most of which is derived from crystalline rocks. Locally, however, in the North Platte valley, as much as one-third of the sand is detritus of volcanic flowrock. There appears to be only moderate weathering of the gravel constituents. Apparently no well-developed soil is present on the gravel but it is capped by an A soil horizon of dark-gray to brown sandy loam and some surface wash, generally 1 to 2 feet thick.

Suggested correlations of the drift of glaciation 3 with various glacial deposits elsewhere in northern Colorado are shown in table 1. Richmond (1960, p. 1374) correlated certain moraines of Rocky Mountain National Park, Colo., with moraines of the Pinedale Glaciation in the Wind River Mountains, Wyo., by use of the following criteria: "Correlation * * * is based on the comparable youthful aspect of the moraines, abundance of boulders at the surface, degree of dissection by axial and tributary streams, loose and sandy texture of the till, freshness and abundance of striations of the boulders, and comparable immature character of the soil. The deposits also represent the youngest major glaciation in both areas". Richmond (1960, p. 1374) pointed out that the terminal moraines of the Pinedale Glaciation in Rocky Mountain National Park "are only partly breached by axial streams, and lateral moraines are but little dissected." Except that striations on boulders are not conspicuous in till of glaciation 3 in western North Park, all Richmond's criteria for correlation with deposits of the Pinedale Glaciation of Wyoming apply to glaciation 3.

RECENT SERIES

CIRQUE DEPOSITS

Cirque deposits shown on the map are found within cirques and as much as half a mile beyond their outer margins. Many of the cirques cut by the glaciers that deposited the tills of glaciations 1 and 2 now contain Recent coarse bouldery material, some of which appears to have been ice transported. Some of this material lies in definite concentric ridges typical of rock glaciers; but some, particularly the coalesced masses beyond the margins of the cirques, is in irregular heaps more typical of terminal moraines. Large amounts of till of glaciation 3 were spread from cirques near Ute Lake and Twin Lake in the Park Range, and much Recent till has likewise been spread from them.

The cirque deposits are distinguished from till of glaciation 3 by their relative topographic position and by their extremely fresh appearance. The contact between the cirque deposits and the till of glaciation 3 is sharp, and the cirque deposits generally rise above the till of glaciation 3 along an embankment as much as 140 feet in height. Large trees, some of them forming a few dense stands, grow locally on the cirque deposits, but for the most part heavy forest is absent, in sharp contrast to very dense forests on till of glaciation 3. The cirque till is mostly boulders of Precambrian granitic and gneissic metamorphic rocks as much as 50 feet in length, derived from adjacent slopes and probably transported less than 1½ miles. Most of the boulders are angular, and some are jointed. Very little fine interstitial material is present. The surface of the cirque deposits has a disordered topography but does not contain water-filled or swampy depressions probably owing to good subsurface drainage. In contrast, till of immediately adjacent deposits of glaciation 3 contains partly rounded boulders that do not exceed 12 feet in length, and all boulders show at least some signs of weathering. Interstitial material is abundant, and it partly buries most of the boulders and supports a soil zone which promotes the heavy forest growth. Water-filled or swampy undrained depressions are abundant.

Richmond (1960, p. 1374–1375) mapped similar deposits in Rocky Mountain National Park, Colo., and referred the deposits to the Neoglaciation. These deposits, as described by Richmond, include moraines and rock glaciers representing two small advances of the ice in the cirques. The older deposits are small and very bouldery; the boulders are blocky and angular; the moraines contain sparse soil and vegetation. The younger deposits are very fresh and blocky; the boulders are unweathered; the deposits contain no soil and almost no vegetation. The cirque deposits of western North Park are similar in most respects to those of Rocky Mountain National Park as described by Richmond.

TRAVERTINE

A single small deposit of travertine is present on beds of the Chugwater, Sundance, and Niobrara Formations just south of Hell Creek in sec. 27, T. 9 N., R. 81 W., at the intersection of a large reverse fault and an anticlinal axis. The travertine apparently was deposited from warm water ascending along the reverse fault. It consists of light-brown limestone that contains fragments of locally derived surficial material. The deposit probably does not exceed 30 feet in thickness. Travertine may be accumulating at the present time in a seep and bog at the south margin of the deposit.

ALLUVIUM

Most of the larger valleys have flat alluvium-covered floors. The maximum width of the valley flats is about 1 mile along Lake Creek near the boundary between Tps. 10 and 11 N. An alluvium-covered flood plain along the North Platte River averages about half a mile in width through much of its length. Little is known about the thickness or composition of the alluvium owing to the absence of either natural or artificial cuts. Generally the upper 1 or 2 feet is a very dark nongravelly loam, apparently rich in organic material. This is underlain by interbedded dark loam and lighter colored layers containing considerable coarse sand, scattered pebbles, and local lenses of gravel.

QUATERNARY UNDIFFERENTIATED

ALLUVIAL-FAN AND PEDIMENT GRAVELS

Thin gravel deposits make up scattered alluvial fans and cap pediments in various parts of the area. The topographic position of most if not all the fans and pediments shows that they were formed prior to the establishment of Recent drainage patterns; they are believed to have formed during the Pleistocene.

The lithology of the gravels reflects nearby source areas. Adjacent to Independence Mountain, the gravels are composed mainly of detritus of Precambrian crystalline rocks derived from boulder conglomerate capping Independence Mountain and from conglomerate in the Coalmont Formation. The fan gravels low on the western slopes of the Delaney Butte highland are composed mainly of crystalline rocks derived from the Precambrian quartz monzonite of Delaney Butte and from the Coalmont Formation; but they also contain minor amounts of materials derived from Mesozoic formations. On the south flank of Peterson Ridge, several small pediments are capped with gravel consisting mostly of volcanic flow rock derived from the North Park Formation and containing small amounts of crystalline rock derived from the Coalmont Formation.

A gully cuts the fan gravel in sec. 26, T. 11 N., R. 81 W. Here the gravel is exposed to a depth of 7 feet and it may be as much as 15 feet thick. It consists of moderately coherent medium to coarse sand, containing pebbles and cobbles as much as 7 inches in length and is capped by an A horizon of soil about 1 foot thick. The gravel is composed entirely of Precambrian crystalline rock derived mostly from the local boulder conglomerate capping Independence Mountain and partly from the Coalmont Formation. The gravel at this locality was once placer mined for gold.

COLLUVIUM, HILL WASH, AND LANDSLIDES

Colluvium, hill wash, and landslides are grouped together for convenience in mapping and are generally shown on the geologic map only where they are geologically significant, where they cover rather extensive areas, or where they mask the structural or stratigraphic relations of the underlying bedrock. Colluvium generally includes poorly sorted material found at the foot of steep slopes and moved principally by gravity. Hill wash generally includes loose weathered material moved downslope by water but not within well-established drainage channels. Landslides include moderately coherent masses of material that slid by gravity, usually down a steep valley wall.

Colluvium and some hill wash cover most of the west slopes of Sheep Mountain and a considerable part of the west slope of the north-trending ridge north of Sheep Mountain. The material is mainly derived from cliffs of Precambrian rocks at the crest of the ridges.

Of particular geologic interest is the colluvium that covers almost all the slope between the east face of Delaney Butte and South Delaney Lake. It is mostly a talus apron consisting of blocks of coarse arkosic sandstone or arkosic breccia, possibly derived from nearly Delaney Butte. (See discussion of Coalmont Formation.) The blocks and rubble are not in place, so they are classed as colluvium rather than as a part of the Coalmont. The deposit lies mainly on nonresistant shale beds of the Benton Shale.

STRUCTURE

MAJOR FEATURES

The mapped area occupies the northwestern part of the North Park basin, a synclinal area lying between the anticlinal Park Range on the west and the Medicine Bow and Never Summer Ranges on the east. Figure 15 shows some of the major tectonic features of North Park. North Park is the northern segment of the North Park–Middle Park basin which resulted from Laramide tectonic activity. North Park and Middle Park are now separated by the Rabbit Ears Range, a transverse west-trending range composed largely of volcanic rocks that originated during a period of late Tertiary tectonic activity. The North Park basin is terminated on the north by a highland area of Precambrian crystalline rocks thrust southward along the west-striking Independence Mountain thrust fault over younger predominantly north-striking sedimentary rocks. Predominantly vertical uplift accompanied by irregular high-angle faulting and some tear fault-

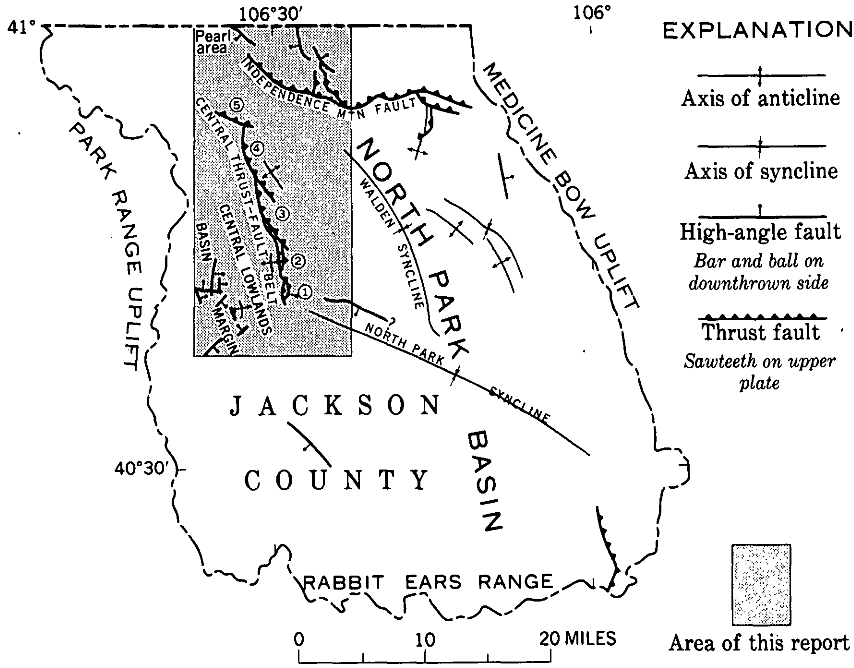

FIGURE 15.—Location of some major tectonic features of North Park. Numbers indicate segments of central thrust-fault zone; 1, Delaney Butte thrust-fault zone; 2, Spring Gulch thrust-fault zone; 3, Sheep Mountain thrust-fault zone; 4, Boettcher Lake thrust-fault zone; 5, Goose Creek thrust-fault zone.

ing marks the margin of the North Park basin along the flank of the Park Range. In the central part of the area, intermediate between the margin and trough of the basin, there is a line of north- to northwest-striking thrust faults—most of them on the crests or flanks of anticlines—producing high scarps, of Precambrian rocks, among which are Delaney Butte and Sheep Mountain. All but the northernmost of these faults dip eastward toward the axis of the basin. Several folds and faults are present in the western lowland area, between the central thrust-fault belt and the basin margin.

The North Park syncline is a narrow trough that extends westward across much of the North Park basin and into the southeastern part of the mapped area. A fault lies parallel to and just north of the syncline.

A possible line of early Laramide faults and folds extending across the mapped area from southwest to northeast is suggested by two pre-Coalmont reverse faults and a probable pre-Coalmont structural and topographical high. A reverse fault in sec. 24, T. 8 N., R. 82 W., strikes northeast, roughly in alinement with the northeast- to north-striking reverse fault just east of Delaney Butte. The projection of this alinement approximately intersects a postulated pre-Coalmont structural and topographic high in the vicinity of the Carter Co. dry hole in sec. 4, T. 10 N., R. 80 W. Further evidence for such a structural trend is lacking owing to the presence of the Coalmont Formation in most of the intervening area.

Structural features of Precambrian rocks were not studied in detail. Regional trends in layered metamorphic rocks in the northern part of the area are indicated by strikes and dips of foliation. Conspicuous folds are present in the large outcrop area of metamorphic rock in the central part of the Pearl quadrangle.

Structural features in the mapped area are depicted in a series of sections (pl. 5) generally drawn normal to the structural trend. The sub-Coalmont structure of that part of the area overlain by the Coalmont Formation, mainly the lowland areas in the northeast and the south, is not known owing to the absence of subsurface information. Only one oil-test hole, the Carter Oil Co. Government-McDannald 1 in the northeastern part of the area was drilled through the Coalmont Formation.

FOLDS AND FAULTS

WALDEN SYNCLINE AREA

The name North Park basin has generally been applied to the northern half of the North Park-Middle Park basin. The basin is bounded by the anticlinal Park Range on the west, the Medicine Bow and Never Summer Ranges on the east, the Rabbits Ears Range on the south, and Independence Mountain on the north. Beekly (1915, p. 90) applied the name North Park syncline to the transverse syncline crossing central North Park. D. M. Kinney (oral commun. 1960) has suggested the use of the name Walden syncline for the axial part of the North Park basin in the northern part of the area in order to avoid confusion in the terminology. The axis of this syncline enters the mapped area in secs. 9 and 16, T. 10 N., R. 80 W., at the eastern boundary of the area (fig. 15) and cannot be clearly defined farther north or west; thus most of the mapped area lies west of the basin axis.

Beds near the west edge of outcrops of the Coalmont Formation in the northeastern part of the area dip 15°–30° E., and the dips diminish gradually eastward as the center of the basin is approached. In the southern part of the area, beds of the Coalmont dip generally 10°–20° E. but are strongly affected near the east boundary of the area by the late Tertiary North Park syncline.

In the northeastern part of the area, surface data suggest general parallelism of the Pierre and Coalmont Formations, but data from the Carter Oil Co. Government-McDannald 1 test hole near the center of the basin suggest a pronounced structural discontinuity between Pierre and Coalmont. Surface measurements of the Coalmont Formation indicate that it should be about 5,000 feet thick in this area, but in the test hole only about 3,300 feet was penetrated. Similarly, the Pierre Shale, which elsewhere exceeds 3,000 feet in thickness, is only about 2,300 feet thick in the test hole. Inasmuch as there are no surface indications of folding or major faulting in the Coalmont Formation in this vicinity, it is assumed that there was pre-Coalmont uplift or faulting, that the Pierre Shale is thin because its upper beds were eroded from a sub-Coalmont hill, and that the Coalmont is thin owing to nondeposition of lower beds on this hill.

INDEPENDENCE MOUNTAIN AREA

The North Park basin is abruptly terminated at the north by a large low-angle thrust fault known as the Independence Mountain fault (fig. 15), along which Precambrian rocks have been thrust southward or westward over rocks ranging in age from Precambrian to Eocene. Independence Mountain is carved from the Precambrian metamorphic rocks of the overthrust plate. A resistant scarp marks the fault through much of its extent, particularly where Precambrian rocks are in contact with nonresistant Tertiary and Cretaceous rocks.

The main segment of the Independence Mountain fault trends approximately northwest and crosscuts older north-trending Laramide folds. The stratigraphic displacement is as much as 12,000 feet where the thrust cuts the central part of the North Park basin. Walters (1957), who first described in detail the geology of the Independence Mountain area, recognized a horizontal movement in excess of 4 miles, measured in a north-south direction. Present mapping indicates that this is the minimum amount of displacement and that the actual movement was considerably greater.

The trace of the Independence Mountain fault trends roughly westward and northwestward from the east boundary of the area to the vicinity of Parsons Draw. Complex imbricate thrust faulting characterizes the fault in the immediate vicinity of Independence Mountain. Just north of Independence Mountain, in the vicinity of Threemile Creek and Parsons Draw, parts of the imbricate thrust plates were removed by erosion, exposing a fensterlike area containing extensive outcrops of the Chugwater Formation and other sedimentary rocks. Part of section *A–A′* (pl. 5) shows the structure across the central part of this area.

The presence of the main lower thrust fault is inferred below the body of boulder conglomerate forming the crest of Independence Mountain, inasmuch as a major discontinuity must separate rocks of the Coalmont Formation on the south side of the mountain from rocks as old as Precambrian on the north side. The observable trace of the fault apparently emerges from beneath the boulder conglomerate about three-fourths of a mile west of Threemile Creek, in secs. 14 and 15, T. 11 N., R. 81 W., and continues northwestward to the base of a prominent scarp at the head of Troutman Draw. There, it turns northward in Precambrian rocks and could not be traced farther.

Small fault slices of sedimentary rock are present at various places along the trace of the Independence Mountain fault. The most conspicuous of these are rocks of the Chugwater Formation, easily identified by their red color. A prominent fault slice of rocks of the Dakota Sandstone crops out in secs. 8 and 9, T. 11 N., R. 81 W.

The dip of the Independence Mountain fault is variable but is generally northeastward at relatively low angles. Exposures in the Parsons Draw area indicate a dip of not more than 5° NE., and in that area the fault trace is irregular and sinuous. In other places, however, the fault plane is much steeper. A layer of breccia exposed where the fault crosses Trapper Gulch in sec. 9, T. 11 N., R. 81 W., is presumed to be parallel to the fault plane and dips 34° NE. The straighter, less sinuous trend of the fault trace in this area also seems to indicate a fairly steep dip.

The most conspicuous of the imbricate faults of the Independence Mountain fault branches from the main fault in the SE¼ sec. 20, T. 11 N., R. 80 W., bends northward under a cover of boulder conglomerate, and then follows the east valley wall of Parsons Draw in a sinuous line to a point just east of the Waldron Ranch where it is terminated by a late Miocene or younger normal fault. Beds of the Chugwater Formation adjacent to the thrust fault dip eastward toward the fault. Sugar Loaf, a small conical hill about half a mile south of the Waldron Ranch, is capped by a thin outlier, or klippe, of Precambrian metamorphic rocks emplaced by the thrust fault.

Three smaller northwest- to north-trending imbricate thrust faults are present on the west side of Parsons Draw below the larger thrust fault. These faults have relatively small stratigraphic displacements and lie entirely within a sedimentary sequence ranging from the Chugwater Formation to the Benton Shale. Each fault is truncated by the next fault to the north, and the uppermost of the three is truncated at both ends by the large imbricate fault; these truncations bring Precambrian crystalline rocks over the sedimentary rocks. The beds in this sequence apparently all dip eastward. Just west of these three imbricate thrust faults in Parsons Draw (in W½ sec. 18, T. 11 N., R. 80 W) is a steep fault whose maximum displacement is estimated to be about 1,000 feet, the east block being downthrown. Along much of the fault, the middle shaly member of the Benton Shale is in contact with the upper part of the Chugwater Formation. The fault truncates a southeast-plunging anticline in the SW¼ sec. 18, T. 11 N., R. 80 W. The attitude of the fault plane is not known; it is arbitrarily shown on sections *A–A′* and *B B′* (pl. 5) as being vertical. That this fault is older than the imbricate thrust faults immediately to the east is evidenced by the termination of its surface trace on the north by one of the thrust faults.

Another imbricate branch of the Independence Mountain fault marks the west margin of the prominent faulted anticlinal ridge that forms the divide between Parsons Draw and Threemile Creek in secs. 12 and 13, T. 11 N., R. 81 W. This fault strikes generally northward and places Precambrian metamorphic rocks against the upper part of the Chugwater Formation. The maximum stratigraphic displacement is estimated to bo about 800 to 1,100 feet, the west block being downthrown. The fault dies out abruptly to the north in the SE¼ sec. 1, T. 11 N., R. 81 W. Southward, the fault presumably continues under the boulder conglomerate to a junction with the main Independence Mountain fault. The anticlinal ridge associated with this thrust fault begins at a point just east of the Waldron Ranch in the NE¼ sec. 1, T. 11 N., R. 81 W., and extends southward and southeastward to the SW¼ sec. 18, T. 11 N., R. 80 W., where it is truncated by the steep fault previously discussed. Precambrian metamorphic rocks mark the axis of the anticline except at the south end, where rocks of the Chugwater, Sundance, and Morrison Formations are present. The anticline is probably related in origin to the bordering thrust fault.

A high-angle reverse fault extends from a point near the Waldron Ranch, at least 3 miles northwestward into Wyoming. The fault cuts Precambrian metamorphic rocks along most of its length, but displaces the Chugwater Formation against Precambrian near its south end. Because stratigraphic markers are absent, the amount of displacement along this fault is not known but it is probably at least 1,000 feet. This fault apparently does not cut rocks of the North Park Formation north of the mapped area, in Wyoming, and therefore may be older than late Miocene.

A narrow embaymentlike outcrop pattern of Chugwater on Precambrian in the NW¼ sec. 36, T. 12 N., R. 81 W., suggests structural movement or possible faulting. Contacts in this locality are too poorly exposed to determine their character, but elsewhere in this area, the Chugwater and the Precambrian apparently are in sedimentary contact.

The latest faults in the Independence Mountain area are two normal faults of relatively minor displacement that place rocks of the

North Park Formation against older rocks east and southeast of the Waldron Ranch.

PEARL AREA

A late Tertiary normal fault forms the contact between the North Park Formation and Precambrian metamorphic rocks along the northeast side of the valley in the vicinity of Pearl. Montagne (1953, p. 103, pl. 1) was the first to map this fault and a similar fault a few miles to the north bordering Cunningham Park in Wyoming, and he postulated that the Miocene rocks of the downthrown sides of these faults were once continuous with more extensive outcrops to the northeast in the upper Saratoga Valley. The vertical displacement of the fault in the Pearl area is not known but is believed to be at least 400 feet. Montagne (1953, p. 103) calculated a throw of more than 800 feet for the nearby Cunningham Park fault in Wyoming. The fault in the Pearl area is marked by a rather conspicuous topographic lineation along part of its length and by a few springs and seeps and small deposits of travertine.

CENTRAL THRUST-FAULT BELT

A belt of major east-dipping thrust faults (fig. 15) extends throughout the central part of the area for a distance of about 16 miles northward to northwestward from Roaring Fork on the south to a point near the Big Creek Lakes in the northwest. Stratigraphic displacements along this line of faults are measured in thousands of feet. These east-dipping thrust faults are probably post-Coalmont in age, although some of the faulting may be pre-Coalmont. The faults are along a line of folds most of which are pre-Coalmont in age, inasmuch as the Coalmont in several places unconformably overlies an erosion surface truncated across the folds. Thrust faulting may have begun prior to the deposition of the Coalmont, possibly as a culmination of the pre-Coalmont folding, and may have been reactivated in post-Coalmont time, but no clear evidence supports this possibility. Thrust faults cut the Coalmont west of Sheep Mountain and Delaney Butte. The large west-dipping reverse fault on the east side of Delaney Butte is probably pre-Coalmont in age.

Tear-faultlike branches divide the thrust-fault belt into five segments that are convenient for discussion purposes. These segments are named, south to north: (1) Delaney Butte thrust-fault zone, (2) Spring Gulch thrust-fault zone, (3) Sheep Mountain thrust-fault zone, (4) Boettcher Lake thrust-fault zone, and (5) Goose Creek thrust-fault zone.

Beekly (1915, p. 84–86, pl. 12) interpreted the faults in this area as high-angle normal faults, as have several other workers. Welsh

(1953), however, interpreted the faults in the Delaney Butte–Sheep Mountain area as high-angle reverse or thrust faults dipping to the northeast. Possibly the best evidence for thrust-fault movement rather than normal-fault movement is the imbricate or compound nature of the fault zones and the intensity of deformation within the zones. Overturned beds within the fault zones are common. All but the northernmost fault zone are associated with asymmetrical anticlines, the steep west limbs of which are commonly obliterated by the faults. Precambrian rocks are exposed at the crest of three of the four faulted anticlines.

Delaney Butte thrust-fault zone.—The Delaney Butte thrust-fault zone is probably the most complex structural feature of the central thrust-fault belt. Sections *I–I′* and *J–J′* (pl. 5) show the structure through Delaney Butte. The butte is bounded on the east by a high-angle west-dipping reverse fault, the west block being upthrown. The fault plane is not exposed but a west dip is inferred from the arcuate pattern of the fault trace, which is slightly convex eastward and from its relation to the topography east and south of Delaney Butte. Precambrian rocks are in fault contact with rocks of the Benton Shale at the place of maximum stratigraphic displacement, which is estimated to be at least 2,000 feet. The fault is concealed by surficial material at its north end and is truncated by a younger fault at its south end. Near the south end of Delaney Butte a northwest-trending high-angle fault places Precambrian rocks against rocks of the Chugwater Formation and is probably a minor fault formed during the upward movement of the reverse-fault block. A north-trending high-angle fault of small stratigraphic displacement offsets contacts of the Morrison Formation, Dakota Sandstone, and Benton Shale along the southeast flank of Delaney Butte in sec. 4, T. 8 N., R. 81 W.

A large compound east-dipping thrust fault is present on the west side of Delaney Butte and locally comprises three imbricate faults. At the place of maximum stratigraphic displacement near the north end of Delaney Butte, stratigraphic displacement is at least 3,500 feet. This thrust fault is younger than the west-dipping reverse fault and presumably cuts the older fault at depth, leaving the core of Delaney Butte as a high and rootless mass of Precambrian rock. The east-dipping thrust fault crosscuts the west-dipping fault southwest of Delaney Butte. Although poorly exposed south of this intersection, the fault presumably continues at least as far south as the Roaring Fork, but its course beyond is problematic. Several possibilities are: it may bend eastward and die out under alluvium in the river valley; it may turn eastward as a tear fault and thus account for the presence of rocks of the Coalmont Formation on the south side of the valley, in

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contrast to Benton, Niobrara, and Pierre on the north side; or it may continue southeastward beneath the Coalmont Formation as a pre-Coalmont fault that, in contrast to the segment at Delaney Butte, was not reactivated in post-Coalmont time.

The south end of Delaney Butte is the remnant of a south-plunging anticline which has been considerably modified by faulting. In the segment of the anticline between the two major faults, Precambrian rocks and rocks of the Chugwater, Sundance, and Morrison Formations are exposed. In the segment east of the west-dipping reverse fault, rocks of the Morrison Formation, Dakota Sandstone, and Benton Shale are exposed. The anticline is primarily of pre-Coalmont age, as eastward-dipping Coalmont strata abut its west flank with marked angular discordance (sections *I–I′* and *J–J′*).

Spring Gulch thrust-fault zone.—Section *H–H′* (pl. 5) shows the structure through the central part of the Spring Gulch thrust-fault zone, and section *G–G′* shows the structure through the northern part. The structure consists of a faulted north-trending anticline and adjoining compound thrust faults. The Spring Gulch zone is the only one of the five major thrust-fault zones in which the bordering anticline is fairly well preserved and is the only one in which Precambrian rocks are not exposed. The oldest rocks exposed at the center of the anticline are in the upper part of the Chugwater Formation. The axis of the anticline is terminated at both ends by the uppermost thrust fault of the fault zone, but a southward plunge is evident. The thrust-fault zone adjacent to the anticline on the west comprises two, and locally three north-striking east-dipping imbricate faults. A short high-angle fault of small stratigraphic displacement is present locally just east of the lowest thrust fault. The faults are covered by surficial material in the valley of Hell Creek, but the lower fault apparently continues northward as the lower one on the west side of Sheep Mountain, and the upper fault is truncated by later thrust faults at Sheep Mountain. The maximum stratigraphic displacement across the Spring Gulch thrust-fault zone may be as much as 3,200 feet in the vicinity of Spring Gulch.

Sheep Mountain thrust-fault zone.—The Sheep Mountain thrust-fault zone is the most conspicuous of the five structural segments of the central thrust-fault belt. Sheep Mountain is a faulted anticline underlain by a northeast-dipping imbricate thrust fault zone on its west side. The core of the mountain consists of Precambrian metamorphic and intrusive rocks, and the east side of the mountain consists of relatively undisturbed sedimentary rocks on the east flank of the anticline. Sections *D–D′*, *E–E′*, and *F–F′* (pl. 5) show the structure of the mountain. A minor thrust fault of small displacement offsets the Precambrian-Chugwater contact on the east flank near Brands Ranch in sec. 10, T. 9 N., R. 81 W. Sedimentary rocks on the west side of Sheep Mountain lie within the thrust-fault zone and are in many places overturned. The original anticlinal structure is best preserved at the north end of the mountain, where a considerable thickness of beds is exposed along the sharply north-plunging axis. At the south end of the mountain, sedimentary beds tend to close around a south-plunging axis but are modified by faulting, and their outcrop is obscured by surficial material. The thrust-fault zone on the west flank of Sheep Mountain is considerably concealed by talus of Precambrian rock derived from the steep front of the overthrust block. Consequently, structural relationships are inferred to a large extent; but there are clearly two major thrust faults, smaller branching faults, and imbricate slices in the zone. The lower of the two major faults places rocks of the Niobrara Formation, Benton Shale, or lower part of the Pierre Shale against rocks of the Pierre Shale or the Coalmont Formation. This lower fault seems to be continuous with the lower fault of the Spring Gulch thrust-fault zone. The upper of the two major thrust faults places Precambrian rocks against the sedimentary sequence, and along most of Sheep Mountain underlies a steep scarp as much as 600 feet high. Rubble of various formations is scattered along the base of the scarp, and small outcrops of Chugwater, Morrison, and Dakota rocks indicate that slices of younger rocks were brought up along the fault. A minor high-angle cross fault breaks the upper thrust plate in secs. 15 and 16, T. 9 N., R. 81 W. A small branch of the upper thrust fault forms the Precambrian-Chugwater contact at the northwest end of Sheep Mountain. A tear-faultlike branch of the upper fault is mostly concealed beneath surficial deposits south of the North Fork of the North Platte River, but aerial photographs show that it swings eastward just south of Higho School and abruptly disappears into a flexure in the upper part of the Niobrara Formation in the NW¼SW¼ sec. 23, T. 9 N., R. 81 W. The two major faults merge near the north end of Sheep Mountain and continue northward as a single fault under much surficial cover to an intersection with Boettcher Lake thrust-fault zone in sec. 19, T. 10 N., R. 81 W. The maximum stratigraphic displacement across the Sheep Mountain thrust-fault zone in the vicinity of the Fliniau Ranch is at least 6,000 feet (section *F–F′*, pl. 5).

Boettcher Lake thrust-fault zone.—Sections *C–C′*, *D–D′*, and *E–E′* (pl. 5) show the structure through the Boettcher Lake thrust-fault zone, which is represented topographically by a prominent north-trending ridge. This fault zone is less complex than, but structurally similar to, the structural units farther south in the central thrust-fault belt. It lies on the west flank of an anticline, strikes northwest to north, and dips east. A short southeast-plunging anticlinal axis is present at the southeast end of the ridge, but it lies no more than 500 feet east of the thrust fault which cuts off the anticlinal axis in the SE¼ sec. 29, T. 10 N., R. 81 W. Apparently only one major thrust fault is present, although a lower fault could lie beneath the extensive surficial cover adjacent to the ridge. The fault is concealed by colluvium or other surficial deposits along most of its length, but the west margin of the Precambrian rocks of the ridge apparently marks the approximate trace of the fault. A small fault slice near the south end of the ridge consists of red beds of the Chugwater. A maximum stratigraphic displacement of at least 3,000 feet across the fault is indicated near the north end of the fault at the mouth of Goose Creek, where Precambrian rock is in contact with the shaly member of the Pierre Shale. The fault is truncated at its north end by the Goose Creek thrust-fault zone. Drag effects along the thrust fault near its south end have produced a small syncline. The axis of the syncline is about 2 miles long and lies from 300 to 900 feet west of the fault. Four minor tear faults, presumably resulting from minor breaking of the thrust-fault plate during major thrust movement, cut the Precambrian rock of the thrust plate and offset the Precambrian-Chugwater contact on the east side of the main ridge. They die out in the Chugwater Formation. One of these minor faults, in the vicinity of Boettcher Lake, extends across the Precambrian outcrop and apparently offsets the trace of the major thrust fault. A fault in secs. 7 17, and 18, T. 10 N., R. 81 W., is small, dying out in the Chugwater Formation; it is reflected in stratigraphically higher beds by an unusually long narrow northwest-trending anticline and an adjacent long narrow syncline (sections *C–C′* and *D–D′*, pl. 5). These elongate folds die out in the Pierre Shale in sec. 27, T. 10 N., R. 81 W.

Goose Creek thrust-fault zone.—The Goose Creek thrust-fault zone is the northernmost segment of the central thrust-fault belt and is marked mainly by the scarp of Precambrian rock bordering the upper valley of the North Fork of the Platte River. This fault zone resembles the others farther south but differs in at least two respects: it is not accompanied by a clearly defined anticlinal structure, and the strike of the fault zone is more westward than northward, averaging about N. 60° W. The fact that its strike is nearly parallel to the strike of the Independence Mountain thrust fault, less than 5 miles to the northeast, suggests a genetic relationship between these two features. Section *B–B′* (pl. 5) shows the structure through this fault zone. Along much of its length the fault zone is covered by colluvium or outwash gravel, but enough is exposed to indicate that it is an imbricate zone. The zone is best exposed in the NW¼ sec. 36, T. 11 N., R. 82 W. (approximate location in an unsurveyed township), where four separate faults, containing slices of rocks of the Benton, Niobrara, Morrison, and Chugwater Formations, are recognized. The underlying Pierre Shale in this vicinity is locally overturned beneath the fault. The stratigraphic displacement at this locality is at least 5,400 feet (section *B–B′*, pl. 5). Sparse outcrops of red beds of the Chugwater farther northwest along the base of the scarp indicate at least two faults in the zone, and there may be others beneath the surficial cover in the valley bottom. The fault zone disappears to the northwest under a thick glacial moraine in the vicinity of the Big Creek Lakes. Near its east end, faults of the zone merge into a single fault which steepens abruptly where it enters Precambrian rocks. The fault extends across a ridge of Precambrian rocks and into the Chugwater Formation in the valley of Lake Creek, where it dies out in the upper part of the Chugwater. Farther east, however, it is expressed in stratigraphically higher beds as a sharply east plunging anticlinal nose which extends as far as the E½ sec. 33, T. 11 N., R. 81 W.

WESTERN LOWLANDS AREA

In the lowlands area (fig. 15) lying between the central thrust-fault belt and the foothills of the Park Range, the Coalmont Formation overlaps the truncated edges of folded or faulted Cretaceous strata. Most structural features of the area thus are pre-Coalmont in age, and hence early Laramide.

Although the broad valley west of the North Fork of the North Platte River and north of Lone Pine Creek is mostly covered by glacial outwash, it appears to be an asymmetrical syncline with a gently dipping west limb and a steep east limb. Sections *C–C′*, *D–D′*, *E–E′*, and *F–F′* (pl. 5) show the structure in this area.

A sharply folded north-trending anticline and a syncline are present in the area between Spring Gulch and Lone Pine Creek. Another syncline, flanking the anticline on the east, is postulated to be present below the Spring Gulch thrust fault (section *G–G′*, pl. 5). The axes of the folds can be traced only 1 to 1½ miles on the surface. The anticline, a fairly tight fold, exposes the shaly member of the Pierre Shale along its crest. A northward plunge is indicated by converging strike readings taken along the south bank of Lone Pine Creek, but the extent of the anticline north of Lone Pine Creek is concealed by outwash. The southern extent of the anticline is likewise obscured by surficial deposits, and it is not known whether the anticline has closure. The syncline flanking the anticline on the west is asymmetrical and has a gently dipping west limb. Rocks of the sandy member of the Pierre Shale are exposed at its center.

Bedrock in the area between Spring Gulch and Roaring Fork is poorly exposed or covered by terrace gravels, and it is not known whether the area contains folds and faults. A flow of hot water found during drilling of the Horton 2 Brands test hole in the SW¼ sec. 31, T. 9 N., R. 81 W., suggests a possible fault at depth.

A series of northward-trending folds and a thrust fault are present in the area of Pitchpine Mountain. Section *K–K′* (pl. 5) shows two synclines and two anticlines, none of which extends for more than 2 miles. The western syncline is shallow and fairly symmetrical; it appears to be doubly plunging, but its north end is covered by glacial till. The western anticline exposes the Morrison Formation along the crest of Pitchpine Mountain. The anticline also appears to be doubly plunging, but like the adjacent syncline its north end is covered by glacial till. The eastern syncline is poorly defined because of a thin cover of rubble from Pitchpine Mountain and poor exposures in the soft shale beds of the Benton Shale. Where the syncline crosses Roaring Fork, near its northern end, it plunges southward. At its south end near Raspberry Creek, it becomes an open fold. The eastern anticline is an asymmetrical double plunging fold with a steep east flank. Conglomerate of the Lytle equivalent of the Dakota Sandstone is exposed along its crest. The fault west of Pitchpine Mountain is interpreted as an eastward-dipping thrust fault. Its maximum known stratigraphic displacement of about 500 feet occurs at Raspberry Creek where the fault places rocks of the Morrison Formation against rocks of the Benton Shale and disappears under alluvium and outwash gravel. The fault probably swings eastward under the surficial cover and cuts across the axis of the western or Pitchpine Mountain anticline.

A narrow outcrop of sandstone and conglomerate of the Dakota Sandstone lies in fault contact with the shaly member of the Pierre Shale in sec. 24, T. 8 N., R. 82 W. The fault, dipping basinward, is interpreted as a thrust or high-angle reverse fault of considerable stratigraphic displacement (section *L–L′*, pl. 5). The fault is exposed for only about 1 mile; it is overlapped to the southwest by the Coalmont Formation and is covered by outwash gravel to the northeast.

BASIN-MARGIN AREA

Much of the contact between Precambrian rocks and sedimentary rocks at the margin of the North Park basin (fig. 15), bordering the Park Range, is covered by glacial till. Exposures are best in the southern part of the area. The contact is very ragged and irregular owing to discontinuous high-angle faults, some of which are offset by tear faults. A normal depositional contact of Chugwater on Precambrian is exposed only in two localities. In general, the sedimentary rocks at the margin of the basin dip rather gently eastward and the structural movement reflected by the basin-margin structural features is that of anticlinal uplift accompanied by high-angle faulting. Sections *E–E′* (pl. 5), and *G–G′*, *K–K′*, and *M–M′* (pl. 5) show the structure of the basin-margin area.

Glacial till covers all sedimentary bedrock along the basin margin north of Ute Creek. Near the south end of Bear Mountain, Precambrian rocks are in fault contact with rocks of the Chugwater, Sundance, and Morrison Formations; the fault probably continues northward along the base of Bear Mountain under a cover of glacial till. Exposures of the fault plane were not seen, but the fault is probably a high-angle reverse fault (section *E–E′*, pl. 5). In a small outcrop about 1 mile south of Bear Mountain and just north of Lone Pine Creek, the Chugwater is in sedimentary contact with Precambrian rock.

Between Roaring Fork and Spring Creek, a high-angle fault which has two branch faults marks the Precambrian-sedimentary rock contact, placing beds of the Chugwater, Sundance, and Morrison against Precambrian rocks. Near the north end of this fault, just south of Roaring Fork, a silicified breccia zone marks the fault and makes a conspicuous spiny ridge; the fact that this ridge is vertical indicates a vertical fault plane at this locality. Near Spring Creek, the main high-angle fault is offset eastward about half a mile along a west-striking tear fault that has considerable horizontal displacement. The offset high-angle fault continues southwestward from the NW¼SW¼ sec. 2, T. 8 N., R. 82 W., for about 1 mile where it is covered by glacial till. In this vicinity, rocks of the Morrison Formation are downfaulted against Precambrian rocks.

The large area of Precambrian outcrop between Lone Pine Creek and Raspberry Creek is cut by several north-striking faults as well as by the west-striking fault near Spring Creek, described above. Many of the faults are mineralized, and commonly contain fault gouge and breccia. They are high-angle nearly vertical or reverse faults, the east block being downdropped (section *K–K′*, pl. 5). The longest of these faults, which crosses Red Canyon (section *G–G′*, pl. 5) and exceeds 3 miles in length, was described by Malan (1957, p. 126–129) and named the Pedad fault.

In the southwest corner of the area a large northeast-striking high-angle, probably reverse, fault places the Morrison Formation against Precambrian rocks and displaces several of the sedimentary formations. Though the fault plane is not exposed, a west dip is inferred from the relation between the trace of the fault and the topography. The fault may be traced from the south boundary of the area to the extreme NW cor. sec. 26, T. 8 N., R. 82 W., where it is covered by glacial till. Two minor northeast-striking west-dipping thrust faults of small stratigraphic displacement are present in this vicinity just east of the large high-angle fault. Another minor thrust fault is present in the E½ sec. 23, T. 8 N., R. 82 W. Section *M–M′* and *L–L′* (pl. 5) show the structure in this part of the area.

NORTH PARK SYNCLINE AREA

The North Park syncline (fig. 15) is a long, narrow trough formed in late Tertiary time. It trends roughly N. 80° W. for more than 20 miles across the central part of North Park. The west end of the syncline, which plunges eastward, extends about 4 miles into the southeast corner of the mapped area; it cannot be traced farther west. The maximum width of the syncline near its west end is about 6 miles.

The structural relations of the rocks across a distance of 2 miles between the west end of the syncline and Delaney Butte are not well known, owing to concealment by alluvium and terrace gravels (section *K–K′*, pl. 5). The synclinal trend is not apparent near Delaney Butte. Also, in this area the Coalmont Formation is anomalously thin, probably less than 2,500 feet. It is assumed that the North Park syncline dies out between the North Platte River and Delaney Butte and that the thin Coalmont section is attributable to periods of nondeposition over a pre-Coalmont topographic high and to erosion of some upper beds prior to the deposition of the North Park Formation. The termination of the syncline and the thinness of the Coalmont in this area, however, may be due to faulting. The major thrust fault west of Delaney Butte cannot be traced farther south or east than the Roaring Fork. It is possible that this thrust fault extends eastward as a tear fault in the valley of the Roaring Fork and crosscuts the synclinal axis west of the Manville Ranch. The contact between the Coalmont Formation and the Pierre Shale shown in the NW¼ sec. 11, T. 8 N., R. 81 W., as a sedimentary contact thus would be a fault contact and part of the Coalmont would have been cut out by the faulting.

A postulated fault of unknown stratigraphic displacement within the Coalmont Formation parallels the synclinal axis and extends from the east boundary of the area to the North Platte River in secs. 7, 8, and 9, T. 8 N., R. 80 W. Near the east border of the area the fault separates north-dipping beds of a small syncline from south-dipping beds of the North Park syncline. Farther west the fault separates divergently striking beds of the Coalmont. Beds north of the fault strike mostly west to S. 70° W.; beds south of the fault strike mostly about N. 70° W. The trend of this fault projected westward across the North Platte River toward Delaney Butte is in alinement with the end of the Spring Gulch thrust fault, but the fault cannot be traced in this intervening area because of cover by alluvium and terrace gravels; therefore, possible relations between the faults are not known. A short presumably high-angle fault crosscuts the small syncline in sec. 4, T. 8 N., R. 80 W., and is terminated at the main fault.

AGE OF DEFORMATION

Early deformation in the area is evinced by the folds in the Precambrian metamorphic rocks. These folds were not studied in detail, but may be the result of more than one Precambrian orogeny, as they are related in origin to the metamorphism that occurred at that time and are completely independent of all structures in the younger rocks.

The area contains no record of the Paleozoic, but on the basis of evidence elsewhere in this region, the Paleozoic presumably was a time of structural quiescence, at least until the Pennsylvanian, when part of the present mountain area of central Colorado including the mapped area was elevated and eroded. This elevated area was part of the so-called ancestral Rocky Mountains or Front Range highland, a structurally positive area that existed intermittently in north-central Colorado throughout most of the Paleozoic. Only a thin wedge of uppermost Permian rocks represents the Paleozoic in the mapped area. If older Paleozoic rocks ever existed, they were destroyed during the Pennsylvanian and Early Permian. The Chugwater Formation, the oldest sedimentary formation in the mapped area, was deposited on an almost flat surface cut over the Precambrian rocks of the old highland.

Pre-Laramide Mesozoic tectonic activity in northwestern North Park was not great, judging by the absence of pronounced angular unconformities within the Mesozoic stratigraphic sequence. However, there was moderate uplift and erosion at times, as indicated by unconformities: (1) within the upper part of the Chugwater Formation, (2) between the Chugwater and Sundance Formations, (3) between the upper and lower members of the Sundance, (4) between the Morrison Formation and Lytle equivalent, and (5) between the Lytle and South Platte equivalents.

Details of early Laramide tectonic activity in northwestern North Park are not well known because the rocks that might indicate them (Cretaceous rocks younger than the Pierre Shale) have been removed by erosion. Although Lovering (1929) suggested that the lithologic change in the Pierre Shale from predominantly shale in the lower part (shaly member) to predominantly sand in the upper part (sandy member) was premonitory of the Laramide orogeny, this may not be so. The change reflects an eastward regression of the sea in early Pierre time (Campanian), and Weimer (1960, p. 14–17) showed that this regression was only the third of four trangressive-regressive cycles of Late Cretaceous deposition in the Rocky Mountain area. All these cycles were of regional extent, and none appear to reflect pronounced local uplift in the area of the present Front and Park Ranges (Weimer, 1960, figs. 8, 9, 10).

Laramide folding and faulting occurred before the deposition of the oldest outcropping Paleocene beds of the Coalmont Formation, and it is assumed that Laramide tectonic activity began during latest Cretaceous (post-Pierre) time. Probably the earliest Laramide event in the North Park area was the uplift of the Park and Medicine Bow Ranges and the consequent formation of the North Park basin between them.

Marginal uplift and probably central downwarp of the basin in latest Cretaceous and earliest Tertiary time was followed by folding and faulting in the western lowlands area and folding in the central thrust-fault belt. The folds in these areas were mostly open folds indicating only moderate compressive tectonic movement; however, local thrust faulting reflected more intense movement. The folds in the vicinity of Pitchpine Mountain, in the vicinity of Spring Gulch, and elsewhere are of moderate amplitude; however, the fault in sec. 24, T. 8 N., R. 82 W., and the west-dipping reverse fault at Delaney Butte have probable stratigraphic displacements of several thousand feet. Many of these various early Laramide structural features were beveled by erosion prior to the deposition of the Coalmont Formation. The oldest outcropping beds of the Coalmont Formation contain detritus from Precambrian rocks. This evidence indicates that the Mesozoic rocks had been eroded and the the Precambrian core of the Park Range was exposed when the basal gravels of the Coalmont were deposited. Sedimentary rocks stripped off the rising Park Range either were not deposited in the adjoining basin, or were, in turn, eroded from the basin before deposition of the Coalmont began in Paleocene time.

In the area southeast of Delaney Butte along the Roaring Fork, the Coalmont apparently overlaps the Pierre, Niobrara, and Benton Formations. In the area between Delaney Butte and Pitchpine Mountain, the Coalmont overlaps the Pierre Shale and the Niobrara Formation. South of Pitchpine Mountain it overlaps the reverse fault which places the Dakota Sandstone against the shaly member of the Pierre Shale. On the west side of Sheep Mountain, gently dipping beds of the Coalmont lie on steeply dipping truncated beds of the Pierre with an angular difference of as much as 66°. The fact that deposition of the Coalmont Formation began in Paleocene time and continued at least into early Eocene time indicates continued uplift of the bordering mountain ranges during Paleocene and early Eocene.

In the area east of the central thrust-fault belt and north of the Roaring Fork, the Coalmont Formation only contains beds of Eocene age. The absence of Paleocene beds there is attributed to the existence of a topographic high on the site of the central thrust-fault belt that either prevented deposition of Paleocene beds or encouraged their erosion.

In northwestern North Park, moderate basinward tilting accompanied by erosion took place in both Eocene and Oligocene time, as suggested by unconformities between the Coalmont, White River, and North Park Formations in the Peterson Ridge area. There the North Park Formation overlaps, at a low angle, truncated beds of the White River Formation and the upper part of the Coalmont Formation. The unconformity at the base of the White River Formation indicates tilting and erosion in middle to late Eocene time; the unconformity at the base of the North Park Formation indicates tilting and erosion in middle Oligocene to late Miocene time.

The last clearly dated major tectonic activity took place after deposition of the North Park Formation in late Miocene time and is dated as latest Miocene or Pliocene. It produced the North Park syncline and the accompanying fault, as well as the normal faults on the north flank of Independence Mountain and in the vicinity of Pearl.

The age of the thrust faults in the central thrust-fault belt and of the Independence Mountain thrust fault is not known, other than that they are post-Coalmont (probably all post-Eocene). No dated Tertiary sedimentary rocks other than Coalmont are present along these faults. The author believes, however, that they may be late Tertiary—latest Miocene or Pliocene. Evidence for dating these faults is only suggestive and is based on their similarities to the trends of the elongate North Park syncline and of the fault in the Pearl area. Both these features are clearly post-North Park in age, and therefore latest Miocene or younger, on the basis of folded or faulted rocks of the North Park Formation. The Independence Mountain thrust fault can be traced northwestward only as far as the NW. cor. T. 11 N., R. 81 W. Only a mile or so northeast of this area the fault near Pearl begins, and it maintains virtually the same northwest strike as the Independence Mountain fault, suggesting that the two may be genetically related. The Pearl fault cuts the North Park Formation. The Goose Creek thrust fault, the northernmost fault in the central thrust-fault belt, is less than 5 miles from the Independence Mountain thrust fault and has the same northwesterly strike as the Independence Mountain fault. The North Park syncline, clearly latest Miocene or younger, and the fault bordering it on the north both strike northwest, a trend compatible with the presumed end of the Spring Gulch thrust-fault zone 2 to 3 miles distant. Surficial deposits cover the intervening area. If the central thrust-fault belt should be genetically related to the North Park syncline, as suggested by similar trends, the faults of central thrust-fault belt would be latest Miocene or younger in age, presumably having formed along a trend of structural weakness which was formed along pre-Coalmont post-Pierre folds.

In the Northgate district, just east of Independence Mountain, Steven (1954; 1960, p. 368, pl. 12) mapped the White River Formation of Oligocene age lying undisturbed across the Independence Mountain fault, and thus indicated a pre-Oligocene age for the fault. The presence of the White River south of the fault in the Northgate district, however, appears equivocal. The deposits in question are poorly exposed and appear to be, in part at least, Quaternary surficial deposits, possibly brought in by streams draining valleys containing outcrops of White River north of the fault. If these deposits are not White River, then the Independence Mountain fault could be younger than White River.

Evidence is lacking for precise dating of the high-angle faults along the basin margin. Fluorspar associated with some of these faults at and near the Crystal fluorspar mine is similar to that found in post-White River faults in the Northgate district of northeastern North Park (T. A. Steven, oral commun., 1962). The faults along the basin margin thus may also be post-White River in age.

ECONOMIC GEOLOGY

No minerals are produced in northwestern North Park at the present time (1962). Some coal and fluorspar have been produced in the past, and gravel is dug locally for road surfacing. There has been much prospecting for oil and gas, copper, gold, and uranium, but with little or no success.

COAL

No commercially important coal reserves are known in northwestern North Park, although small amounts have been produced from two mines in the area—the Mitchell mine in the SE¼ sec. 24, T. 8 N., R. 82 W., and the Monahan mine in the SE¼ sec. 31, T. 10 N., R. 81 W. The Mitchell mine produced coal of mediocre quality from beds in the lower part of the Coalmont Formation; the Monahan mine produced coal of relatively good quality from beds in the sandy member of the Pierre Shale.

The Coalmont Formation contains very little coal through most of its outcrop area in northwestern North Park, and what little there is, is in thin and lenticular beds. Elsewhere in North Park, the Coalmont locally contains abundant coal. The bed from which coal was produced at the Mitchell mine was named the Mitchell bed by Beekly (1915, p. 107). It occurs in a zone of brown carbonaceous shale and cannot be traced on the surface beyond the immediate vicinity of the mine; it is believed to lens out within a quarter of a mile of the mine. Beekly (1915, p. 107) reported another opening in the Mitchell bed half a mile north of the Mitchell mine, but no outcrop is apparent at the present time (1962). The entry of the Mitchell mine is caved and inaccessible. Beekly (1915, p. 107–108) visited the mine in 1911 and gave the following description:

> The total thickness of coal exposed in the mine is 10 feet 4 inches, of which the lower 2 feet 4 inches is separated from the remainder of the bed by a 10-inch shale parting. * * * The shale parting is used as the floor of the mine, and about 7 feet of the upper bench is mined, the upper foot being left for a roof throughout most of the workings * * *. Of the 8-foot bench the upper 3½ feet is clean and glossy black but breaks up badly in mining; the next lower 2½ feet is laminated and soft, and the lowest 2 feet is hard and glossy black, with a pronounced woody structure. The output of the mine has been used by Mr. Mitchell and neighboring ranchmen for domestic fuel and is said to have given fairly satisfactory results.

Analyses of two samples from the Mitchell mine (U.S. Bur. Mines, 1937, p. 84–85) show that the coal is subbituminous C rank.

Thin discontinuous lenticular coal beds occur in an east-thinning wedge of nonmarine beds in the sandy member of the Pierre Shale in the vicinity of the Monahan mine. Beekly (1915, p. 108) named this coal bed the Monahan bed. Coaly beds can be traced only a few hundred feet along the strike in the vicinity of the mine, and they dip eastward where they are presumably cut off by the zone of thrust faults on the west side of Sheep Mountain. Coal was not seen in the Pierre Shale elsewhere in the area. The mine, now caved and inaccessible, was examined in 1911 by Beekly (1915, p. 108), who gave the following description of the coal:

> This bed is 4½ feet thick and is made up of clean, hard coal, free from partings. At the mine the bed strikes N. 15° W. and dips slightly north of east. On the hillside above the mine a streak of coal bloom on the surface indicates the presence of a thin coal bed about 50 feet above the Monahan bed. This upper bed was not accessible for measurement, but is thought to be below minable thickness * * *. The development work was done by William Monahan and consists of a slope of 125 feet on the dip of the bed. The work was mainly for prospecting purposes, and the small output of the mine has been used for domestic fuel by ranchmen of the vicinity. The coal is soft and practically worthless to a depth of 75 feet or more from the outcrop, but at the working face of the slope it is hard, black and clean and of comparatively good quality.

Analysis of a single sample from the Monahan mine (U.S. Bur. Mines, 1937, p. 84–85) shows that the coal is subbituminous B rank.

GRAVEL

Gravel resources are abundant and have been utilized locally for road surfacing. Principal sources of gravel are the older terrace gravels and outwash and glaciofluvial gravels of glaciations 2 and 3. Some of the alluvial fans may also provide suitable sources for gravel. The younger gravels should be more suitable for road construction than the older ones, inasmuch as they contain a smaller proportion of highly weathered, easily disintegrated material. Gravels in the southeast corner of the area are composed predominantly of waterworn volcanic flow rocks; the gravels elsewhere are composed predominantly of waterworn granite and metamorphic Precambrian rocks.

Riprap used in dams constructed at Lake John in 1959 by the Colorado Game and Fish Department is hard blocky sandstone taken from the lower sandstone unit of the South Platte equivalent.

OIL AND GAS

No oil or gas has been discovered to date (1962) in northwestern North Park. The presence of three small productive fields in eastern North Park suggests, however, that the entire North Park basin may be potentially favorable for future oil and gas discovery. In the productive fields of eastern North Park, oil is or has been produced from the lower sandstone unit of the South Platte equivalent ("Dakota"), the Lytle equivalent ("Lakota sand"), sandstone beds in the Morrison Formation, and the lower member of the Sundance Formation ("Entrada" or "Sundance sand"). Gas is or has been produced from the upper sandstone and siltstone unit of the South Platte equivalent ("Muddy sand"), the lower sandstone unit of the South Platte equivalent ("Dakota sand"), and the Lytle equivalent ("Lakota sand").

Only four significant test holes for oil and gas have been drilled in northwestern North Park as of 1962. These are listed below:

Name	Year drilled	Location			Surface formation	Lowest formation penetrated	Total depth (feet)
		Sec.	T.N.	R.W.			
Carter Government-McDannald 1.	1956	SW¼SE¼ 4	10	80	Coalmont	Chugwater	7,500
Johnson Big Horn Ranch 1.	1953	NW¼NW¼ 27	10	81	Niobrara	do	2,381
Cabeen 1 Carlstrom State A.	1959–60	SW¼SW¼ 29	9	81	Pierre	Sundance	4,250
Horton 2 Brands	1953	SW¼SE¼ 31	9	81	Niobrara	Morrison	1,075

Oil and gas possibilities.—Oil and gas in eastern North Park are produced in the North McCallum, Battleship, and Canadian River fields, all located on anticlines. These anticlines are asymmetrical, the axial planes dipping basinward (westward); and probably all are cut by basinward-dipping thrust faults on their steep east flanks. Similar structural features are present in northwestern North Park, except that basinward dips are toward the east. The most prominent of these anticlines are in the central thrust-fault belt (fig. 15), but in all these, potential oil reservoir beds have been eroded from the crests of the anticlines.

The two small anticlines in the vicinity of Pitchpine Mountain are structurally favorable for oil and gas accumulation, but they have been eroded down to or below rocks of the Dakota Sandstone, which contain the most important oil-bearing strata in eastern North Park.

The long narrow anticlinal nose just east of Boettcher Lake was unsuccessfully tested for oil by the Johnson Big Horn Ranch 1 test hole. Surface outcrops indicate that this anticlinal nose has little or no structural closure. A north-trending tightly folded anticline occurs in secs. 21 and 28, T. 9 N., R. 81 W. (fig. 4; pl. 5, section *G–G'*). The surface formation is Pierre Shale. Inasmuch as surficial deposits cover both ends of the anticline, it is not known whether the anticline has any structural closure, although converging strike readings suggest a north plunge near Lone Pine Creek.

Possible geophysical prospecting for favorable anticlinal structures not evident from surface mapping should be directed to examination of areas covered by Quaternary surficial deposits, areas overlain by the Coalmont Formation, and areas underlying thrust-fault plates. The valley of the North Fork of the North Platte River from its north end south to Ute Creek is almost completely covered by till and outwash. Although bedrock structure in this area is probably monoclinal or broadly synclinal, the area may include folds comparable to those farther south in the Spring Gulch-Lone Pine Creek area. Morainal material and outwash may conceal folds in the underlying bedrock in other areas as far south as Roaring Fork.

Inasmuch as the Coalmont Formation unconformably overlies beveled pre-Tertiary folds and faults in certain parts of the area where the base of the Coalmont can be seen, it is likely that pre-Tertiary structural features are present elsewhere beneath the Coalmont. The large area of Coalmont outcrop west of the North Platte River and south of Roaring Fork may possibly overlie such folds and faults.

Folds may be present below some of the larger thrust-fault plates in the area, although recognition of such folds from geophysical data might be difficult. The faulted anticline revealed in the fenster just north of Independence Mountain suggests that similar structural features exist elsewhere below the Independence Mountain thrust plate. The local occurrence (pl. 5, section *G–G'*) of folds genetically related and adjacent to the thrust fault near Hell Creek suggests the possibility of folds below other thrust faults in the central thrust-fault belt.

Fault traps have not been tested in North Park, although some oil shows found in drilling in various parts of North Park may have been localized by faults. Probably the most likely sites for fault entrapment of oil in northwestern North Park are along faults of the central thrust-fault belt. Fault traps might be present where potential oil reservoir beds at depth are cut off and sealed by overriding thrust plates.

Potentially productive sandstone units such as the lower member of the Sundance Formation and the sandstone of the Lytle Formation vary considerably in thickness probably owing to irregularities of the erosion surfaces on which they were deposited, but neither unit is known to pinch out entirely in the area. However, Saterdal (1957, p. 124) noted a complete pinchout of the "Lakota sand" (Lytle equivalent) in the Canadian River oil field of eastern North Park, about 13 miles east of the mapped area.

Coarse lenses or wedges of sandstone and conglomerate in the Morrison Formation provide potential traps for oil. Such beds are widely and irregularly distributed within the Morrison. The possibility of stratigraphic entrapment in the upper part of the South Platte equivalent is suggested by a facies change in the middle dark shale unit and the upper sandstone and siltstone unit. Sandstone and siltstone beds ("Muddy sand") become thinner and fewer in number, and shale beds become thicker and less sandy from south to north in the mapped area. The regional relations indicate that a similar facies change takes place from east to west across the northern part of the basin. However, permeabilities throughout this part of the South Platte equivalent are generally low, and even if updip wedgeouts of sandstone or siltstone beds are present west of the basin axis, lack of good permeability may have prevented oil accumulations. Oil is not produced from the upper part of the South Platte equivalent elsewhere in North Park, but it is the source of gas produced at the Canadian River field.

Fractured zones in the Codell Sandstone Member of the Benton Shale ("Frontier sand") have yielded oil shows or minor oil production to wells outside the mapped area in North Park. This rock otherwise generally lacks permeability because it is composed mainly of recrystallized clastic limestone. In the outcrop area just east of Pitchpine Mountain on the banks of Roaring Fork, the Codell Sandstone Member contains beds of nonresistant presumably permeable sandstone which are seemingly absent from formation outcrops elsewhere. Should similar beds be present in the subsurface, traps might be present.

COPPER AND GOLD

Copper.—Numerous abandoned copper-prospect pits and small mines in Precambrian metamorphic rocks are present near Pearl in the northwestern part of the area, but little copper has been produced. Prospecting apparently began about 1899 and a smelter was built a few years later in anticipation of commercial development of the copper deposits. The smelter was never operated, however, and most prospecting had ceased several years prior to 1911 when Beekly (1915, p. 116–117) examined the area. A few tons of ore was shipped from the Wolverine mine in 1916 and 1917.

A. C. Spencer (1903) briefly described some of the Pearl copper deposits. According to Spencer the principal copper minerals are sulfides—mostly chalcopyrite but also some chalcocite and bornite. Pyrite is commonly associated with the copper sulfides. Other sulfides including sphalerite and galena are present in small amounts. Malachite is present on some of the weathered material in prospect dumps. Spencer (1903, p. 164–169) observed that the sulfide minerals commonly replace biotite and hornblende in metamorphic gneiss and in pegmatite. The ore minerals are mostly disseminated in the host rock or are present as small concentrations in biotite- or hornblende-rich segregations. Minor sulfide mineralization is also present in fractures in the pegmatite and in adjacent brecciated gneiss.

According to Ogden Tweto (written commun., 1961), the Pearl copper deposits apparently belong to the group of high-temperature sulfide deposits of Precambrian age found in generally small bodies scattered through the Precambrian terranes of Colorado.

Gold.—Minor amounts of placer gold have been taken from gravels in the vicinity of Independence Mountain. Most of the gravel containing the gold is derived from the local boulder conglomerate. Small placer operations have been attempted near the head of Threemile Creek on Independence Mountain in sec. 23, T. 11 N., R. 81 W., in gravels of the local boulder conglomerate. A gravel deposit marking the site of a long-abandoned placer operation may still be seen in the upper part of Placer Draw. Gravel in this placer was derived from an alluvial fan on the lower slopes of Independence Mountain in sec. 26, T. 11 N., R. 81 W. The placer had been abandoned when it was examined in 1911 by Beekly (1915, p. 117), who made the following statement:

A small amount of gold was mined some years ago in the south-central part of T. 11 N., R. 81 W., by washing a quantity of the sand and gravel which covers portions of the south slope of Independence Mountain * * *. A pipe line was constructed at great expense from Big Creek Lake in T. 11 N., R. 82 W., and the placer was operated for a short time. The gold content of the gravel was much less than had been anticipated, however, and the project was soon abandoned as unprofitable.

Part of the pipeline mentioned by Beekly is still in use; it is the present Independence Ditch, which brings water from Big Creek Lakes to the head of Lake Creek in the SE¼ sec. 1, T. 11 N., R. 82 W. (approximate location in an unsurveyed township) and provides Lake Creek with much of its water supply.

FLUORSPAR

Fluorspar deposits in the Northgate district in northeastern North Park, about 5 miles east of the mapped area, are among the largest in the Western United States (Steven, 1960, p. 325), and there has been considerable prospecting for fluorspar in the Park Range in northwestern North Park. Many prospect holes contain fluorite in veins and breccia zones associated with the high-angle faults cutting Precambrian rocks in the area between Lone Pine and Raspberry Creeks. Many of the fluorspar prospects in the mapped area were originally opened in the 1920's. Fluorspar has been produced from only one mine in the area, the Crystal fluorspar mine in the NW¼ sec. 10, T. 8 N., R. 82 W. (approximate location in an unsurveyed township), operated by the Crystal Fluorspar Mines Co. The mine was opened about 1945 and was closed in 1949. Only about 800 tons of fluorspar was produced.

URANIUM

Considerable prospecting for uranium was done during the early 1950's in northwestern North Park but without notable success. Claims were staked in Precambrian rocks and in the Morrison Formation, Dakota Sandstone, Quaternary alluvium, and probably others. Locations of a few of the prospect pits are shown on the geologic map.

Malan (1957, p. 126–133), of the U.S. Atomic Energy Commission, described some of the more promising of the uranium prospects in the area. In the area of Precambrian granitic rocks between Lone Pine Creek and Raspberry Creek, uranium-bearing fluorspar and unidentified uranium minerals associated with the fluorspar are present along many of the high-angle faults. The uranium content of samples tested ranged from 0.05 to 0.34 percent U_3O_8. A small uranium-bearing peat deposit in Quaternary alluvium near the Brands Ranch, sec. 10, T. 9 N., R. 81 W., yielded samples containing 0.014 to 0.046 percent U_3O_8. The uranium in the peat was probably derived from spring water.

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INDEX

[Italic page numbers indicate major references]