Geology and Coal Resources of the Livingston Coal Field Gallatin and Park Counties Montana

By ALBERT E. ROBERTS

GEOLOGY OF THE LIVINGSTON AREA, SOUTHWESTERN MONTANA

GEOLOGICAL SURVEY PROFESSIONAL PAPER 526–A

A study of the Eagle Sandstone (Cretaceous), with special emphasis on its regional correlation, variation in lithology, and coal resources

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1966

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

GEOLOGY AND COAL RESOURCES OF THE LIVINGSTON COAL FIELD GALLATIN AND PARK COUNTIES, MONTANA

By Albert E. Roberts

ABSTRACT

The Livingston coal field lies in the east-central part of Gallatin County and the west-central part of Park County, southwestern Montana, and is at the junction of the south end of the Bridger Range near Bozeman, Mont., the west end of the Beartooth Range near Livingston, Mont., and the north end of the Gallatin Range. The mapped area of about 420 square miles includes eight 7½-minute quadrangles. The maximum relief in the area is about 4,900 feet. The lowest point, at an altitude of 4,435 feet, is in the Livingston quadrangle, along the broad terraced valley of the Yellowstone River in the eastern part of the area. The highest point, at an altitude of 9,342 feet, is in the Mystic Lake quadrangle, on the north end of the Gallatin Range.

The oldest rocks in the mapped area are Precambrian gneiss, granite, and schist exposed in the cores of the Canyon Mountain and Sourdough Creek anticlines and in the uplifted blocks of the Beartooth and Bridger Ranges. The overlying sedimentary rocks range in age from Middle Cambrian to Tertiary and are more than 20,600 feet thick. Only the Silurian and Triassic Systems are not represented. Rocks of Paleozoic age are 3,050 feet thick and are generally exposed along the axes of the major anticlines. Rocks of Jurassic age are 700 feet thick and form a prominent narrow belt along the flanks of anticlines. Rocks of Cretaceous age are 11,775 feet thick and are expcsed along the flanks of anticlines and in the troughs of synclines. More than 4,900 feet of rock of Paleocene age fills the southern part of the Crazy Mountains basin, and 220 feet of sedimentary rock and more than 3,000 feet of volcanic rock of Eocene age cap the ridges in the northern part of the Gallatin Range.

The predominant structural features of the area are three major en echelon folds, which are partly overturned and overthrust. The coal beds generally dip about 40°–50° and are overturned in several localities. Large thrust and high-angle reverse faults, many normal faults, and tension fractures formed during and (or) after the folding. Intrusions of diorite are associated with some of the normal faults and tension fractures.

Commercial coal beds in the Livingston coal field are in the Eagle Sandstone of Late Cretaceous age and are distributed mostly in two well-defined zones that are persistent throughout the field. The coals are high-volatile A, B, and C bituminous in rank, and some are of coking quality.

The coal reserves were estimated as of January 1, 1965, to total more than 300 million short tons. These reserves are in beds 14 inches or more thick and are within 3,000 feet of the surface. The coal reserves are categorized by individual bed and by township and range, and are classified according to the quantity and reliability of the available data and the characteristics of the coal and associated rocks.

INTRODUCTION

PRESENT INVESTIGATION

Major chemical, smelting, and sugar-refining plants that require a large annual tonnage of coke have been built in eastern Idaho, in Montana, and in northern Wyoming. The Livingston coal field, in southwestern Montana, is centrally located to these industries and is, therefore, the subject of renewed interest. The only other Montana coal fields that have a history of coke production are the Electric field near Gardiner and the Belt field near Great Falls.

The Livingston coal field was studied during the years 1955–61. The primary objectives of the study were to appraise the coal resources and to obtain geologic data essential to other economic studies of the Crazy Mountains basin of southwestern Montana. During that period, unfortunately, the mines were closed, and most of the underground workings were either caved or flooded; therefore, field investigations of the coal deposits were concentrated on surface exposures.

Geologic maps of the eight quadrangles in the Livingston coal field have been published separately (Roberts, 1964a–h). Field mapping was done on aerial photographs at a scale of 1:23,600. Geologic data were transferred from the annotated photographs to the topographic base maps by means of Multiplex projectors—precision stereoplotting instruments that were also used in making the base maps. Compilation was at a scale of 1:15,840, and publication was at a scale of 1:24,000.

Stratigraphic units were measured by planetable and alidade and by Brunton and tape traverses. The coal beds were usually measured at intervals of a mile or less along their lines of outcrop (pl. 1) and were traced individually through areas of poor exposure by their relative position within persistent carbonaceous zones (pl. 2) and by the association of persistent sandstone beds. Representative samples were collected usually from the middle of each lithologic unit. Description of these units includes megascopic and microscopic determinations of physical properties. Rock colors are described by comparison with the National Research Council "Rock-Color Chart" (Goddard and others, 1948).

This report describes the stratigraphy and evaluates the coal resources of the Eagle Sandstone of the Livingston coal field as a part of the U.S. Geological Survey's program to evaluate the fuel resources of the United States. It is hoped that the information presented will aid in the mining and utilization of the coal, which is one of the natural bases for the potential industrial growth of this region.

PREVIOUS INVESTIGATIONS

Coal in the Livingston coal field was first known in 1867 and was examined by geologists of the Geological Survey of the Territories (Hayden, 1872, p. 46; 1873, p. 113). One of the principal functions of the Northern Transcontinental Survey, organized in 1881, was to examine and extend the bituminous coal fields near Bozeman and Helena, Mont., and near Wilkinson and Carbonado, Wash. (Pumpelly, 1886, p. 691). Accessible steam coal in large supply was vital for the railroads as well as for the growth of mining and other industries in the Northwest Territory. George Eldridge (1886, p. 746–751) was in charge of the Northern Transcontinental Survey party that examined and reported on the Bozeman (Livingston) coal field. Weed (1891, p. 349; 1892, p. 521) also reported on the Bozeman (Livingston) coal field, and Iddings and Weed (1894) discussed the stratigraphy of the area and the distribution of the coal-bearing rocks. Storrs (1902, p. 464), in a summary report on the coal fields of the Rocky Mountains, briefly described the coal-bearing area near Livingston, which he referred to as the Yellowstone field. Calvert (1912a, p. 393–400), reporting on his 1908 visit to the coal districts near Livingston and Trail Creek, briefly discussed the Livingston coal field districts. Stebinger (1914a, p. 908) also briefly discussed the area in a generalized summary of the coal fields of Montana. These reports are publications of reconnaissance studies, and none of them give a detailed description of the geology, the coal deposits, or the coal resources.

The productive areas of the Livingston coal field were first designated the Bozeman and Trail Creek coal fields by Eldridge (1886, p. 748). Weed (1891, p. 349; 1893, p. 19), in his description of the "Laramie coal measures" at Livingston, referred to this area as the Bozeman coal field. Storrs (1902, p. 463–464) very briefly discussed the coals between Bozeman and Livingston as a part of the Yellowstone coal field, and the coals in the valley of Trail Creek as the Trail Creek coal field. Calvert (1912a, p. 384) preferred to drop the previous names of Bozeman and Yellowstone and applied the name Livingston coal field to the area paralleling the Northern Pacific Railroad. He retained the name Trail Creek field for the area in Trail Creek Valley (Calvert, 1912a, p. 385). Stebinger (1914a, p. 908) preferred Trail Creek field as a geographic name for the area midway between Bozeman and Livingston. The mining areas of the Livingston coal field were described by Calvert (1912a, p. 393) as the Chestnut, Cokedale, Meadow Creek, and Timberline districts. The names of all except the Meadow Creek district were derived from the largest mine in each district. The Meadow Creek district contained several mines, but these were all small and relatively minor producers. In this report the name "Livingston coal field" is retained for the entire coal-bearing area; the Meadow Creek and Chestnut districts described by Calvert (1912a, p. 397) are combined as the Meadow Creek district; the Trail Creek field of Calvert (1912a, p. 398) is described as a district of the Livingston coal field; and the Bridger Canyon district is added.

ACKNOWLEDGMENTS

Through the generous cooperation of George R. Powe, Northern Pacific Railway Co., records on operations of some of the mines in the area were made available to the author. George H. Bottamy, Bess H. Booker, Merrill G. Burlingame, Fred J. Martin, Elizabeth M. McKean, Edward Miller, Frank M. Olson, Martha M. Palffy, Frank M. Woodward, and Llewellyn E. Williams provided information concerning mines and prospects in the area, and the author is grateful for their many kindnesses.

Field assistance was given in 1955 by J. S. Hollingsworth, in 1956 by J. F. Treckman, in 1957 by C. J. Galvin, in 1958 by G. C. Cone, and in 1961 by A. L. Benson.

Much of the early history of the mines of the Livingston coal field was compiled, with the assistance of Marguerita McDonald and Evelyn D. Roberts, from the following newspapers: Avant Courier, Bozeman Times, Bozeman Weekly Chronicle, and the Livingston Enterprise.

GEOGRAPHY

LOCATION AND ACCESSIBILITY

The Livingston coal field lies near Livingston, in the east-central part of Gallatin County and the west-central part of Park County, southwestern Montana, at the junction of the south end of the Bridger Range near Bozeman, Mont., the west end of the Beartooth Range, and the north end of the Gallatin Range. The Gallatin Range—bounded on the east by Paradise

Valley, through which the Yellowstone River flows, and on the west by the valley of the Gallatin River—extends northward to the south end of the Bridger Range. The mapped area of about 420 square miles lies between long 110°30′ W. and 111°00′ W. and lat 45°30′ N. and 45°45′ N. (fig. 1).

The transcontinental line of the Northern Pacific Railway crosses the Livingstone coal field from east to west, and the Yellowstone Park Branch of the Northern Pacific runs from Livingston southward to its terminus at Gardiner. A branch line of the Chicago, Milwaukee, St. Paul, and Pacific Railroad (starting at Three Forks) serves Bozeman. Livingston is at the junction of U.S. Highways 10 and 89 from east to west and north to south, respectively. U.S. Highway 191 courses south from Bozeman to West Yellowstone and then to Idaho. An excellent system of State and county roads provides year-round access to the main highways and principal cities.

TOPOGRAPHY AND DRAINAGE

The youthful to submature topography of the Livingston area is largely the result of stream erosion of rocks having varying degrees of resistance. In the eastern part of the area, the surface has been modified by Quaternary glaciofluvial deposits. The maximum relief in the mapped area is about 4,900 feet. The lowest point, at an altitude of 4,435 feet, is in the Livingston quadrangle—along the broad terraced valley of the Yellowstone River in the eastern part of the area. The highest point, at an altitude of 9,342 feet, is in the Mystic Lake quadrangle, on the north end of the Gallatin Range.

In the northern part of the mapped area, the topography is submature and consists of low rounded hills whose altitudes range from 4,600 to 7,900 feet above sea level. This part of the area is underlain by Upper Cretaceous and Paleocene nonmarine sedimentary rocks that include much poorly indurated shale and siltstone. The topography of the central part of the area is characterized by northwest-trending ridges of indurated Paleozoic rocks and contiguous valleys in the easily eroded Cretaceous rocks. Here, the highest points are Mount Ellis, 8,331 feet; Canyon Mountain, 8,038 feet; Pine Mountain, 7,669 feet; and Hogback Ridge, 6,617 feet. The sides of the valleys, particularly those of Trail Creek, show the effect of landsliding and slumping of the poorly indurated Cretaceous sedimentary rocks. In the southernmost part of the area, which is underlain chiefly by volcanic flows and breccias and by volcanic-derived sedimentary rocks, the youthful topography consists of sharp north-trending ridges which range in altitude from 6,400 to 9,300 feet.

Pleistocene glaciation formed many of the land features in the easternmost part of the area (Weed, 1893; Horberg, 1940). Alpine glaciers extended down the valleys along the west end of the Beartooth Range, whose summit rises more than 5,000 feet above the Yellowstone River valley bottom.

The eastern part of the mapped area is within the Yellowstone River drainage system. The Yellowstone River heads in Yellowstone National Park, in northwestern Wyoming; it flows northwestward from the park for about 25 miles and then turns northeastward to Livingston, where it makes a large bend and flows eastward across the State. The main tributaries to the Yellowstone River in the mapped area are Trail, Billman, and Fleshman Creeks from the west, and Pine, Pool, Deep, and Suce Creeks from the east. Maximum flows of the Yellowstone River at Livingston have ranged from 825 to 30,600 second-feet; minimum flows ranged from 590 to 13,590 second-feet. The annual mean discharge is 2,609,400 acre-feet, and, with the exception of 4 years in the period of record, the highest flows have been in June.

The western part of the mapped area is within the East Gallatin River drainage system. Rocky and Bridger Creeks merge with Bozeman Creek to form the East Gallatin River near Bozeman. Hackett, Visher, McMurtrey, and Steinhilber (1960) discussed the ground-water resources of this area.

CLIMATE AND VEGETATION

Topography is a major influence on the climate of the Livingston area. In general, the mountainous lands are both wetter and cooler than are the broad valleys. The annual precipitation at Livingston is about 14 inches; the recorded range for 1925–34 is 25.79–8.07 inches. Rainfall is heaviest during May, June, and (to lesser degree) September. The last killing frost of spring at Livingston occurs on about May 17, and the first frost of fall occurs on about September 21; thus, the average frost-free season is 127 days. The average monthly temperature and precipitation at Livingston and Bozeman during the 10-year period 1948–57 are shown in figure 2.

The mountain areas probably receive more precipitation than is indicated by the records compiled at valley observation points. Snow depths during winter commonly range from 5 to 13 feet and average about 7 feet.

The forest cover in the report area is largely confined to U.S. National Forest and Northern Pacific Railway Co. lands. Timber is limited to a vertical zone in the mountainous areas, where moisture is more abundant and soil conditions are favorable. The zone extends downward from timberline for a vertical distance of 2,500 feet. Trees of commercial value are the Lodgepole pine and Douglas-fir. Of lesser economic importance are Engelmann spruce, juniper or redcedar, pon-

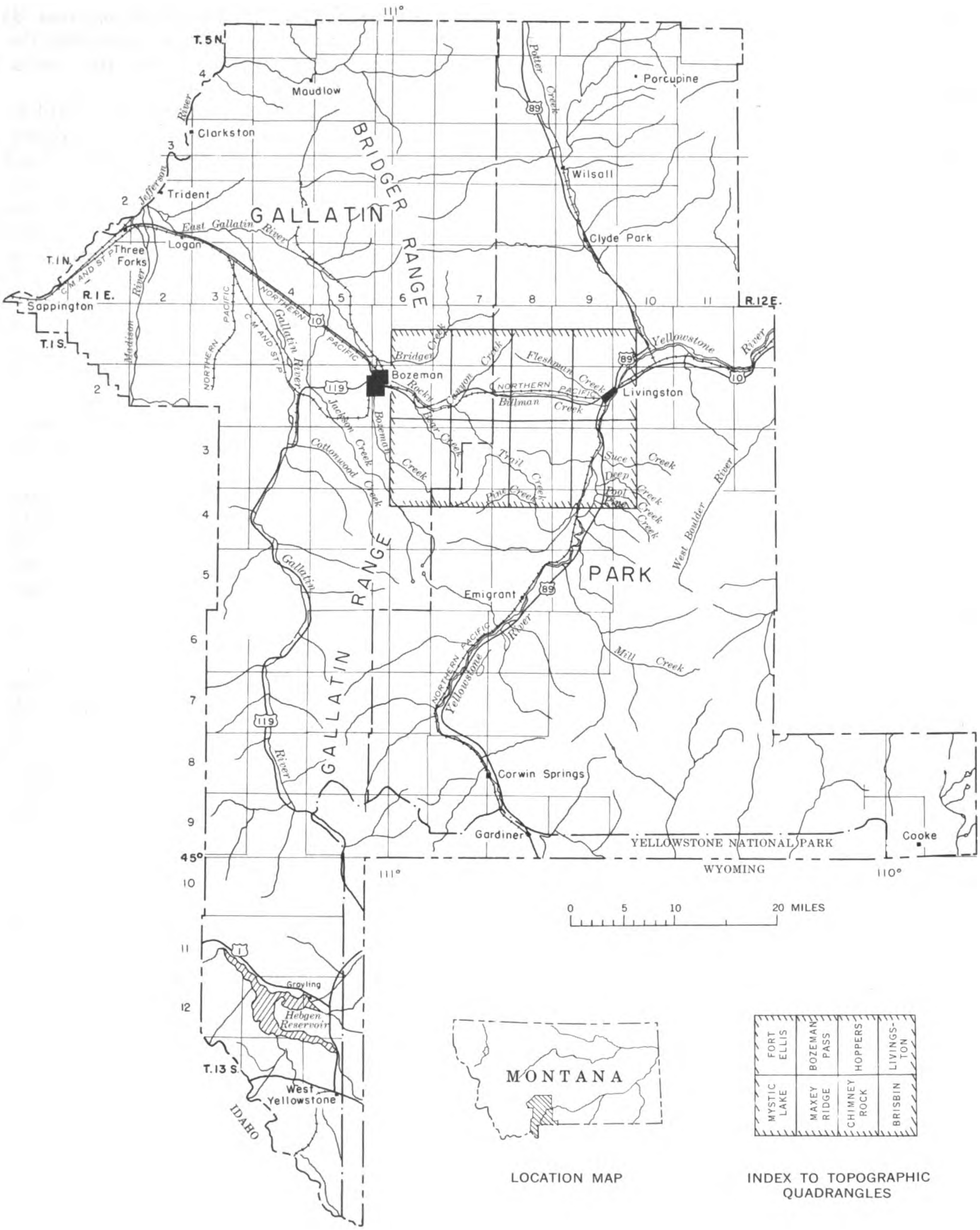


FIGURE 1.—Location of the area mapped in the Livingston coal field, Gallatin and Park Counties, Mont.

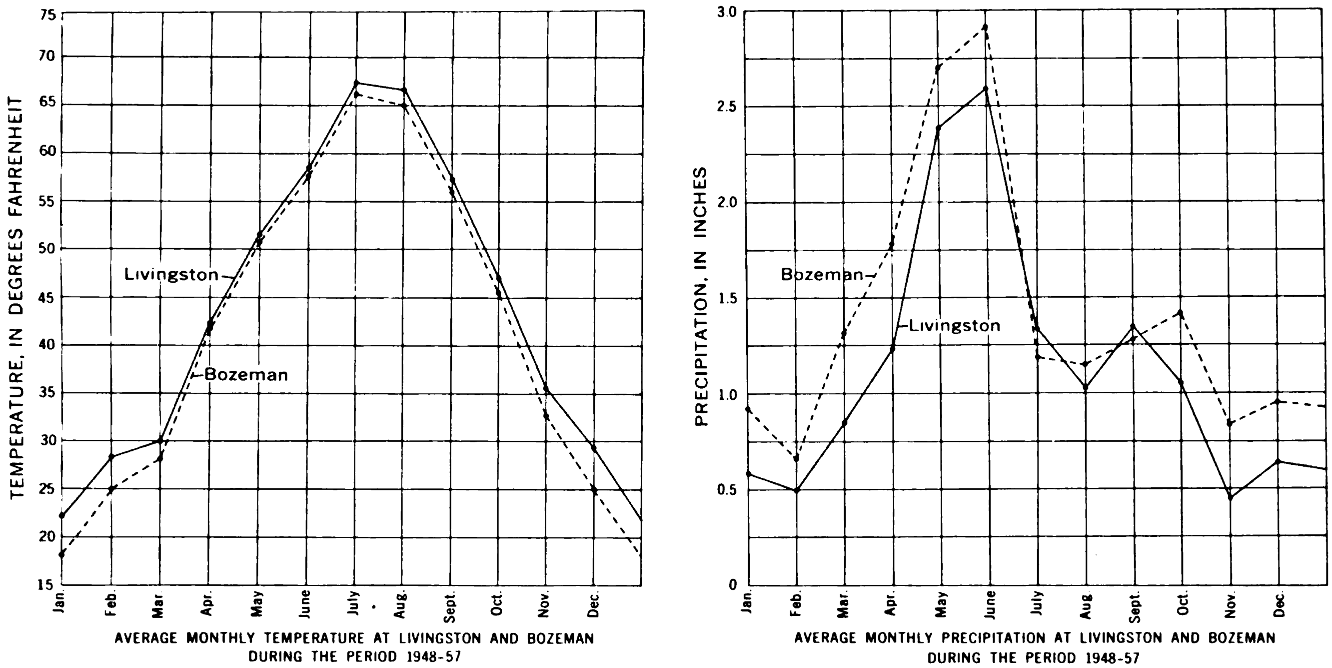


FIGURE 2.—Average monthly temperature and precipitation at Livingston and Bozeman during 1948–57. From U.S. Weather Bureau (1948–57).

derosa pine, white pine, limber pine, and alpine fir. Valleys and rolling foothills flanking the Bridger and Gallatin Ranges are largely unforested. Generally, cottonwood, aspen, and other deciduous trees mark the courses of the rivers and perennial streams.

ECONOMY

Livingston and Bozeman, the two largest cities in or near the mapped area, are the economic centers and county seats for Park and Gallatin Counties, respectively. During the early years of their growth, Livingston, at the east limit of the commercial coal deposits, and Bozeman, at the west limit, both benefited economically from the coal mining industry. Since the turn of the century, however, these cities have been supported primarily by farming and dairying, stock raising, lumbering, transportation, educational institutions, and tourism.

STRUCTURE

The oldest rocks in the mapped area are Precambrian gneiss, granite, and schist exposed in the cores of the Canyon Mountain and Sourdough Creek anticlines and in the uplifted blocks of the Beartooth and Bridger Ranges. The sedimentary rocks in the area range in age from Middle Cambrian to Tertiary and are more than 20,600 feet thick (Roberts, 1964a–h). Only the Silurian and Triassic Systems are not represented. The Paleozoic rocks are 3,050 feet thick and are generally exposed along the axes of the major anticlines. Rocks of Jurassic age are 700 feet thick and form a prominent narrow belt along the flanks of anticlines. Rocks of Cretaceous age are 11,775 feet thick and are exposed along the flanks of anticlines and in the troughs of synclines. More than 4,900 feet of Paleocene rock fills the southern part of the Crazy Mountains basin, and 220 feet of sedimentary rock and more than 3,000 feet of volcanic rock of Eocene age cap the ridges in the northern part of the Gallatin Range. From the latter part of the Late Cretaceous through the Paleocene, a gradual transition in depositional environment took place, as shown by successive deposition of the marine Telegraph Creek Formation, the brackish-water marine and nonmarine Eagle Sandstone, and the continental deposits of the Livingston Group and the Fort Union Formation.

Late in the Santonian Stage of Late Cretaceous time, epeirogenic arching began in western Montana, and the Eagle seas regressed to the east. This period of orogeny and erosion was also marked by volcanism that formed the thick Elkhorn Mountains Volcanics (Klepper and others, 1957, p. 31). After withdrawal of the Late Cretaceous Eagle seas from western Montana, the area east of the Bridger Range and north of the Beartooth Range gradually warped downward to form the Crazy Mountains basin.

The Crazy Mountains basin is elongated northwestward and is approximately 40–70 miles wide and 130 miles long. The basin is asymmetrical and contains more than 13,000 feet of sedimentary rock in the western part, derived predominantly from andesitic volcanic rock of the Elkhorn Mountains. Deposition in this part of the basin occurred during the remainder of Late Cretaceous and Paleocene time (Roberts, 1963, p. B86). On the west and southwest the basin is bounded by the Bridger Range and the Beartooth Range tectonic blocks, which were formed by uplift and by basinward thrusting, respectively eastward and northeastward. Between the Bridger and Beartooth Ranges near Livingston is an area of en echelon folds whose northwest-oriented axes parallel the axis of the Crazy Mountains basin.

The Livingston area was relatively stable in comparison with the Bridger Range to the west and the Beartooth Range to the east. As the uplifted Bridger and Beartooth blocks were forced basinward, arcuate northwest-trending en echelon folds, each convex to the southwest, formed in the Livingston coal field. Folding in the Livingston area continued until the major anticlines became asymmetric—dips on the southwest flanks became steeper than those on northeast flanks. The Canyon Mountain anticline was intensely folded and became recumbent on its southwest flank.

During the folding, lateral movement of competent sandstone beds in the Eagle Sandstone caused local folding and shearing of the intervening incompetent coal beds (fig. 3). Squeezing that accompanied this movement produced lenticular beds similar to boudinage structure. Local areas underwent considerable squeezing and shearing, and the coal beds in these areas were transformed to lenses of friable slickensided coal.

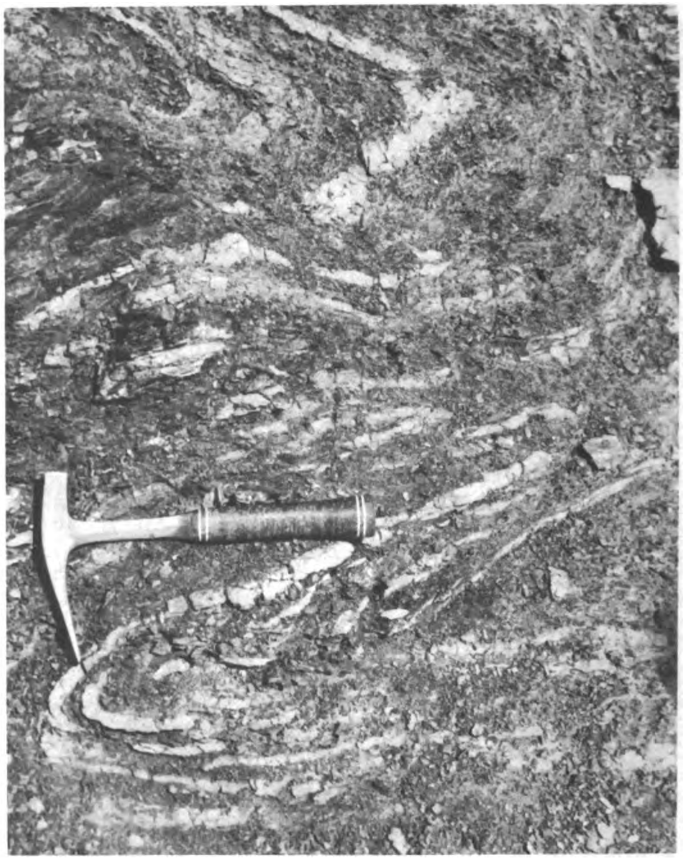


FIGURE 3.—Big Dirty coal bed (NW¼NW¼ sec. 26, T. 2 S., R. 8 E.), Livingston coal field, Montana. Folding and shearing shown in the incompetent coal bed resulted from adjustment during lateral movement of overlying and underlying competent sandstone beds.

The crustal forces, which resulted from deep-seated compressional forces, continued to act until the competent rocks ruptured; and large thrust and high-angle reverse faults formed in an en echelon arrangement parallel to the folds. The general direction of dip on the plane of these faults was west to south, depending on the proximity to the Bridger or Beartooth Ranges. The high-angle reverse faults are characteristically steep but probably become flatter at depth. Faults along the southwest flank of the Canyon Mountain anticline indicate several pulses of thrusting and intervening periods of erosion (Roberts, 1964a, b).

Compressive forces continued to move the Bridger block eastward and the Beartooth block northeastward; and folding continued in the Livingston area, but with less magnitude than before. The folding of the thrust plates changed the general dip on the plane of these faults at this time to basinward, or northeastward.

Extensive erosion accompanied the folding, and by Late Cretaceous time the Bridger and Beartooth uplifts were truncated to expose Precambrian rock. The basal conglomerate of the Fort Union Formation in the Livingston area, of very Late Cretaceous age, contains rock fragments derived from Precambrian, Paleozoic, and Mesozoic rocks (Roberts, 1963, p. B89).

During deposition of the Fort Union Formation in the northern part of the Livingston coal field, erosion continued in the southern part. Later, the southern part was covered by volcanic rocks or by volcanic-derived sedimentary rock, which, at their northern extent near Chimney Rock, Mont., are coarse clastics and pyroclastics. Indentification of spores and pollen from a local carbonaceous claystone near the base of this volcanic sequence by R. H. Tschudy (written commun., 1962) and petrographic comparison of the overlying rocks with stratigraphic units of known age in the northern Absaroka Range and Yellowstone National Park area, Wyoming, indicate a Wasatchian and Bridgerian provincial age (Wood and others, 1941) assignment.

In post-Paleocene time, after the folding and thrust faulting, rocks in the Livingston area were intruded—

generally along tension fractures or faults—by small dikes and sills of diorite. These intrusions are few, and only a very small number cut the coal-bearing rocks. Consequently, the loss of coal reserves in the Livingston coal field due to the effects of intrusion was small; however, in the Mountain Side mine, sec. 21, T. 2 S., R. 7 E., the east limit of the workings is in an area of natural coke produced by a diabase dike.

Nearly vertical faults—along which the movement was predominantly vertical—characterized the closing tectonic activity in the Livingston coal field. These are normal faults and are predominantly parallel to structural axes. The displacement along these faults ranges from a few feet to several thousand feet; however, on faults that cut the coal beds, the displacement is generally a few feet to several tens of feet. The faults become more numerous near the crests of the anticlines (pl. 1).

Tectonic events that occurred in or adjacent to the Livingston coal field after the deposition of the coal-bearing Eagle Sandstone probably were closely related or were virtually contemporaneous. They occurred in the following sequence:

1. Uplift accompanied by erosion of the area west of the field (now occupied by the Boulder batholith) and withdrawal of the Eagle seas to the east.
2. Volcanic activity and erosion of the uplifted area and downwarping of the Crazy Mountains basin.
3. Folding and (or) uplifting of the Bridger and Beartooth Ranges.
4. Basinward thrusting of the Bridger and Beartooth Ranges forming en echelon folds having northwest trending axes in the Livingston area.
5. Continuation of folding until the anticlines became asymmetric with the steeper dip on the southwest flank—the Canyon Mountain anticline became recumbent.
6. Failure of the folds by thrusting and high-angle reverse faulting.
7. Several pulses of thrusting and intervening periods of erosion.
8. Continuation of folding but with less magnitude than previously—thrust plates were folded.
9. Extensive erosion followed by volcanic activity south and southeast of the Livingston area.
10. Intrusion by diabasic dikes and sills, generally along tension fractures or parallel to structural axes.
11. Normal faulting, predominantly parallel to structural axes.

STRATIGRAPHY OF THE EAGLE SANDSTONE

The Eagle Sandstone exposed in the Livingston coal field consists of sandstone, siltstone, intermediate phases of transitional sandy siltstone and silty sandstone, and coal beds. This coal-bearing sequence makes up the Eagle Sandstone of the Montana Group of Late Cretaceous age (pl. 2). The Eagle Sandstone in this area consists of lagoonal, estuarine, and terrestrial deposits laid down near ancient shorelines. These strata show an alternation of marine nearshore and offshore facies interfingered with nonmarine facies. Deposition of these types results in facies of different lithology but of the same age and in facies of similar lithology but of different age.

Weed (1899, p. 2) named the Eagle Sandstone from outcrops along the Missouri River at the mouth of Eagle Creek in Chouteau County, north-central Montana. At the type locality the formation consists of three units: an upper unit of thin-bedded sandstone, a middle unit of siltstone, and a lower unit of hard massive persistent sandstone. The lower unit was later named the Virgelle Sandstone Member of the Eagle Sandstone by C. F. Bowen (Stebinger, 1914b, p. 62) from outcrops along the Missouri River near the town of Virgelle, Mont.

Weed (1893, p. 11) separated the nonvolcanic coal-bearing formation (Eagle Sandstone) from the overlying volcanic-derived sediments of his Livingston Formation (Cokedale Formation of Roberts, 1963, p. B89) on the basis of lithology and believed the two were separated by an unconformity. Stone and Calvert (1910, p. 761) correctly described Weed's Livingston Formation as conformably overlying the coal beds at Livingston. Roberts (1957, p. 47; 1963, p. B90) arbitrarily designated the top of the arkosic sandstone that overlies the Cokedale coal bed as the contact between the Cokedale Formation and the underlying Eagle Sandstone. Some andesitic sandstones are in the upper part of the Eagle Sandstone, and a few arkosic sandstones and coal beds are in the lower part of the Cokedale Formation; however, in the Livingston area this boundary is the best mappable contact. The difference between physical and chemical properties of the coals in the upper part of the Eagle (bituminous-coking) and the lower part of the Cokedale (lignite-noncoking) also supports this boundary assignment. The thin black chert-pebble conglomerate that in many places marks the top of the Eagle or base of the Claggett throughout much of the Montana was not found in the section at Cokedale.

The Eagle Sandstone conformably overlies the Telegraph Creek Formation of Late Cretaceous age (fig. 4) throughout the Livingston coal field. The upper part of the Telegraph Creek consists of thin-bedded to massive light-olive-gray very fine grained calcareous arkosic

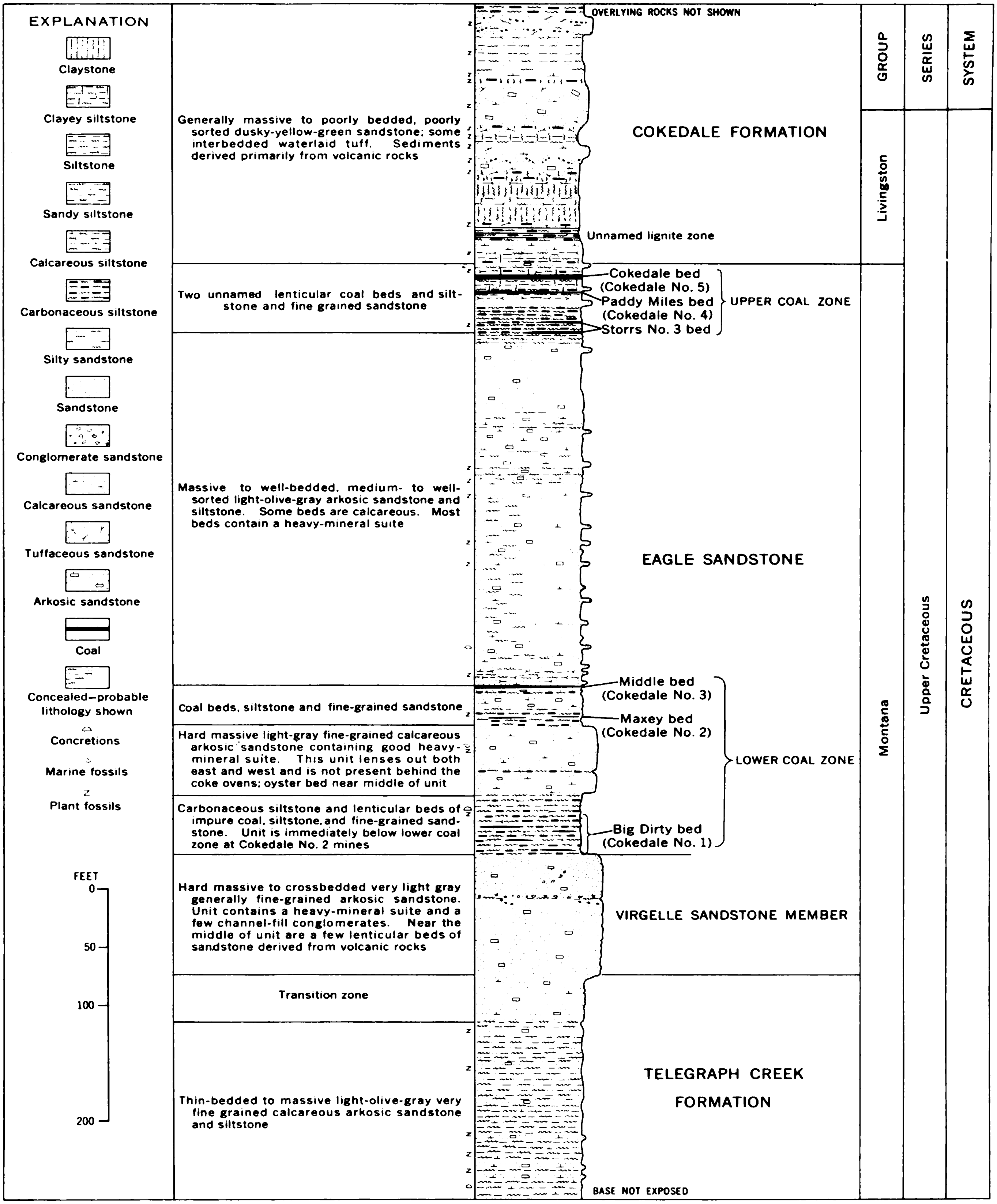


FIGURE 4.—Eagle Sandstone, NW¼ sec. 26, T. 2 S., R. 8 E., at Cokedale, Park County, Mont.

sandstone and siltstone. The boundary between the two formations is gradational.

The Cokedale Formation of Late Cretaceous age (fig. 4) conformably overlies the Eagle Sandstone in the northern part of the report area. The Cokedale consists of generally massive to poorly bedded poorly sorted dusky-yellow-green sandstone and claystone interbedded with some water-laid tuff, bentonite, carbonaceous claystones, and lignite. The sediments were derived mainly from volcanic rocks of andesitic composition. The difference in the lithologies of the Eagle Sandstone and the Cokedale Formation is conspicuous; however, the boundary is not marked by an abrupt change.

The thickness of the Eagle Sandstone within the Livingston coal field ranges from 515 to 860 feet and averages about 600 feet (pl. 2). At Cokedale, 9 miles west of Livingston, where the Eagle Sandstone is best exposed, it is 645 feet thick, including the 110-foot-thick Virgelle Sandstone Member at its base (fig. 4). The sandstone beds are very light gray to yellowish gray and of variable composition and texture. In some localities they are massive and coarse grained; in others, banded or laminated and fine grained. Generally the indurated beds are calcareous.

In the southern part of the area, the Eagle Sandstone ranges in thickness from 525 to 575 feet (pl. 2) and is composed mostly of light-colored sandstone and siltstone. The middle and upper parts of the formation are softer and thinner bedded than is the lower part. Massive light-gray sandstone, averaging 10–15 feet in thickness, is interbedded throughout the formation.

North and east of Cokedale the Eagle Sandstone thins to 470 feet at Loweth, Mont., and to 245 feet at Columbus, Mont. (J. R. Gill, oral commun., 1962). Northwest of Cokedale in the Bridger Range, the Eagle is about 600 feet thick at the south end of the range and thins to about 100 feet thick at the north end (McMannis, 1955, p. 1388, 1407). Southward from Livingston the Eagle Sandstone thickens, and at Mount Everts near Gardiner it is 780 feet thick (G. D. Fraser, oral commun., 1963). West of the report area the Eagle has been eroded (Robinson, 1963, p. 58). The overlying Livingston Group and the Fort Union Formation also thin progressively northward and eastward from Livingston (Roberts, 1963, p. B87). To the east and north, rocks of the Eagle, Livingston, and Fort Union also become finer grained, better sorted, lighter in color, and less andesitic in composition.

Tertiary flows, flow breccias, and related sedimentary deposits unconformably overlie the Eagle Sandstone in the southern part of the report area. At the north extent of the these rocks, near Chimney Rock, Mont., the stratigraphic section consists predominantly of conglomerates, flow breccias, agglomerates, and mud flows, which are rock types similar to those deposited near the periphery of large volcanic piles. At the base of the section is 160 feet of cliff-forming coarse conglomerate composed predominantly of fragments of dacitic volcanic rock and lesser amounts of Precambrian igneous and metamorphic rocks and Paleozoic and Mesozoic sedimentary rocks. Carbonaceous claystone is present locally at the base of this conglomerate (W. J. McMannis, written commun., 1962). It contains plant spores and pollen that were identified by R. H. Tschudy (written commun., 1962) as of Wasatchian provincial age. The cliff-forming conglomerate is overlain by 60 feet of loosely consolidated slope-forming conglomerate that contains only fragments of volcanic rock, which is generally of andesitic composition. A sequence, several thousand feet thick, of andesitic flows, flow breccias, agglomerates, and mud flows overlies the slope-forming conglomerate. The Wasatchian provincial age of the claystone at the base of the section and petrographic comparisons of the overlying rocks indicate that the lower conglomerate is either a lateral facies of part of the "early acid breccia" of Hague (1899), part of the Reese Formation of Calvert (1912b, p. 412), or part of the Cathedral Cliffs Formation of Pierce (1963, p. 9) of Wasatchian provincial age. The same evidence indicates that the upper conglomerate and overlying rocks are equivalent to the "early basic breccia" of Hague (1899) of Bridgerian provincial age in the northern Absaroka Range and Yellowstone National Park area, Wyoming.

LITHOLOGIC COMPOSITION

The Eagle Sandstone at Cokedale consists generally of two parts: the lower half is massive indurated crossbedded sandstone that is intercalated with beds of coal and carbonaceous siltstone and shale; the upper half is well-bedded poorly indurated sandstone and siltstone that is intercalated with beds of coal and carbonaceous siltstone or shale (fig. 4). All gradations between sandstone and siltstone exist, but sandstone beds predominate. The sandstone generally is very fine grained to fine grained, subangular to subrounded, and moderately to well sorted.

The lower half of the Eagle Sandstone at the Cokedale No. 1 mines consists of four generalized parts—two carbonaceous units and two sandstone units (fig. 4).

The carbonaceous unit in the lower part of the Eagle Sandstone, described as the lower coal zone, consists of coals, carbonaceous siltstones, and fine-grained sandstones. In the middle of the lower coal zone is a hard massive light-gray fine-grained calcareous arkosic sandstone that contains a heavy-mineral suite, as well as oysters, *Inoceramus*, and large plant fragments. This unit lenses out along the strike and is not present north of the coke ovens in sec. 26, T. 2 S., R. 8 E., or at the Cokedale No. 2 mines in sec. 21, T. 2 S., R. 8 E. A representative sample from the middle of this unit contained a trace of coarse sand, 11.2 percent medium sand, 61.3 percent fine sand, 17.5 percent very fine sand, and 10.0 percent silt and clay. The sample was 15.7 percent carbonate by weight and contained a heavy-mineral suite. The heavy minerals, listed approximately in order of decreasing abundance, are zircon, tourmaline, garnet (colorless), brookite, rutile, apatite, staurolite, epidote, muscovite, and corundum (colorless).

The Virgelle Sandstone Member at the base of the Eagle Sandstone consists of hard massive to crossbedded very light gray generally fine-grained arkosic sandstone. It contains a few channel-fill pebble-conglomerate zones and, near the middle of the member a few lenticular beds of sandstone derived from volcanic rocks. A representative sample from the middle of the Virgelle contained 0.08 percent medium sand, 14.96 percent very fine sand, and 18.25 percent silt and clay. The sample was 23.75 percent carbonate by weight and contained a heavy-mineral suite. The heavy minerals, listed approximately in order of decreasing abundance, are zircon, tourmaline, muscovite, biotite (green and brown), apatite, diopside, corundum (colorless and red), rutile, staurolite, garnet (pink), hornblende (green), gold, and epidote(?).

The upper half of the Eagle Sandstone is divisible into two generalized parts (fig. 4): an upper carbonaceous unit (or upper coal zone) and a lower sandstone unit. The carbonaceous unit consists of coals, carbonaceous siltstones, and sandstones. The sandstone unit consists of massive to well-bedded medium- to well-sorted light-olive-gray arkosic sandstone and siltstone. The indurated beds are generally calcareous. A representative sample from the middle of this unit contained material in the following Wentworth (1922) grain scale sizes: 38.9 percent fine sand, 51.0 percent very fine sand, and 10.1 percent silt and clay. The sample was 33.4 percent carbonate by weight and contained a heavy-mineral suite. The heavy minerals, listed approximately in order of decreasing abundance, are zircon, tourmaline, augite, rutile, staurolite, apatite, anatase, muscovite, corundum (colorless), epidote, leucoxene, and garnet (colorless).

Petrographic examination of the Eagle Sandstone indicates that it consists of as much as 50 percent quartz and lesser amounts of plagioclase, feldspar, rock fragments of fine-grained andesites(?), microlite and microporphyritic andesites(?), quartzite, chert, and carbonate. Most quartz grains show straight to slightly undulose extinction and few vacuoles and inclusions, which suggests a plutonic source; some, however, show a strong undulose extinction and have no inclusions or vacuoles, which suggests a metamorphic source. The plagioclase is mostly andesine, and the feldspar is mostly orthoclase.

Carbonate is abundant. Apparently it is secondary after feldspar and is therefore difficult to distinguish from primary carbonate. In the following stratigraphic descriptions, carbonate, whether primary or secondary, was noted as calcareous under cement.

Traces of silica and zeolite minerals are also present as a cement. Other minerals present are biotite, muscovite, garnet, hematite, magnetite, ilmenite, leucoxene, allanite, tourmaline, chlorite, pyrite, apatite, epidote, sericite, and clay. Many clastic beds in the Eagle contain an abundance of carbonaceous material in the matrix.

A few tuffs are present in the Eagle Sandstone, and they generally consist of a fine-grained matrix containing abundant plagioclase microlites and laths and numerous cavites filled with carbonate and silica. Only a few samples contained more than 1 percent pyrite.

DESCRIPTION OF STRATIGRAPHIC SECTIONS

The following two sections of the Eagle Sandstone, measured near Livingston and Cokedale, are probably typical of the Eagle in this region. In reference to the bedding of the rocks, the following standard was used to indicate thicknesses: Massive, greater than 4 feet; thick-bedded, 2–4 feet; medum-bedded, 6 inches–2 feet; thin-bedded, 2–6 inches; very thin bedded, ½–2 inches; platy, 1/16–½ inch; and fissile, less than 1/16 inch. The term "arkosic" is used for the sandstone composition of quartz, plagioclase, and feldspar and does not imply sole derivation from a granitic terrane. The source of the sandstones is unknown; however, there are some indications that most of the quartz and feldspar was derived from Precambrian granite, gneiss, and schist and that the plagioclase was derived from younger igneous rocks.

SECTION 1.—*Eagle Sandstone on north side of Miner Creek in NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.*

[Measured by Albert E. Roberts and J. Stewart Hollingsworth in 1955]

	Ft	in.
Cokedale Formation (Upper Cretaceous).		
Eagle Sandstone (Upper Cretaceous):		
104. Sandstone, thick-bedded, indurated (slight ridge former), calcitic, very fine grained, light-olive-gray (5*Y* 6/1), arkosic. Weathers to pale-olive (10*Y* 6/2) slabs about 3–6 in. thick. Sorting, fair. Quartz grains comprise 50 percent. Contains heavy-mineral suite	3	0

SECTION 1.—*Eagle Sandstone on north side of Miner Creek in NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.*—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	Ft	in.
103. Siltstone, thick-bedded, tuffaceous, olive-gray (5*Y* 4/1), and thin interbedded very fine grained sandstone Weathers to dusky yellow (5*Y* 6/4). Contains fragments (fine grained) of volcanic rocks and plant fragments. Unit poorly exposed	2	0
102. Siltstone, very carbonaceous, tuffaceous, clayey (roof)	5	0
101. Coal (Cokedale coal bed or locally the Cokedale No. 5 bed), attitude N. 84° W., 40° NE	5	0

	in.
Siltstone, very carbonaceous, tuffaceous	2
Siltstone, tuffaceous	1
Bone	3
Coal	8
Siltstone, altered, tuffaceous, carbonaceous	2.5
Coal	11
Siltstone, altered, tuffaceous, carbonaceous	.5
Bone	5
Coal	19
Bone	2
Siltstone, very carbonaceous, clayey	6

	Ft	in.
100. Siltstone, massive, light-gray (*N*7), clayey. Poorly exposed. Weathers to light-olive-gray (5*Y* 6/1) soil	6	0
99. Sandstone, indurated (slight ridge former), very fine grained, dusky-yellow-green (5*GY* 5/2). Sorting, fair. Weathers to yellowish orange (10*YR* 7/6). Rock appears to be transition of Eagle Sandstone and Livingston Group lithologies. Weathers along fractures (N. 60° W.) and bedding planes. Attitude N. 80° W., 40° NE	2	0
98. Siltstone, thick-bedded, light-olive-gray (5*Y* 6/1), clayey, carbonaceous. Weathers to moderate yellowish brown (10*YR* 5/4). Small granule-size grains near base	3	0
97. Coal (probably Paddy Miles coal bed or locally the Cokedale No. 4 bed)	1	0

	in.
Bone	3
Coal	9

	Ft	in.
96. Siltstone, medium-bedded, olive-gray (5*Y* 4/1). Weathers to moderate yellowish brown (10*YR* 5/4)	1	6
95. Siltstone, very carbonaceous (almost bone)		2
94. Siltstone, massive, pale-olive (10*Y* 6/2), tuffaceous. Weathers to moderate greenish yellow (10*Y* 7/4). Forms a crumbly soil	4	0
93. Sandstone, indurated, slabby, crossbedded, very fine grained, yellow-green (5*GY* 6/2); slight ridge former. Irregular thickness, from 4 to 6 ft	5	0

SECTION 1.—*Eagle Sandstone on north side of Miner Creek in NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.*—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	Ft	in.
92. Siltstone, massive, olive-gray (5*Y* 4/1), carbonaceous. Poorly exposed	13	0
91. Siltstone, thick-bedded, medium-dark-gray (*N*4), carbonaceous. Weathers to light olive gray (5*Y* 6/1). Slightly more indurated than overlying siltstone. Breaks with conchoidal fracture. Manganese stain common on fracture surfaces. Spheroidal weathering	2	0
90. Coal, probably Storrs No. 3 coal bed (upper part); not described, as bed is burned along the outcrop from the valley to top of the hill	2	0
89. Siltstone, very carbonaceous, grayish-brown (5*YR* 3/2), weathers to pale yellowish brown (10*YR* 6/2). Contains plant fragments	1	0
88. Siltstone, massive, greenish-gray (5*GY* 6/1). Weathers to yellowish gray (5*Y* 8/1). Poorly exposed	6	0
87. Coal, probably Storrs No. 3 coal bed (lower part)	2	0

	in.
Bony coal	1
Coal	8
Siltstone, very carbonaceous	3
Coal	8
Bony coal	1
Siltstone, very carbonaceous	3

	Ft	in.
86. Siltstone, massive, light-olive-gray (5*Y* 6/1), tuffaceous; weathers to yellowish gray (5*Y* 8/1). Poorly exposed	11	0
85. Sandstone, massive, very light gray (*N*8), fine-grained, arkosic. "Salt-and-pepper" appearance. Contains heavy-mineral suite. Somewhat porous; considerable limonitic staining near top of unit. Slightly crossbedded. Sorting, fair. Massive spheriodal weathering. Weathers to yellowish gray (5*Y* 7/2)	6+	0
84. Concealed; probably fine-grained very light gray arkosic sandstone	36	6
83. Sandstone, massive, very light gray (*N*8), fine-grained, arkosic. "Salt-and-pepper" appearance. Contains heavy-mineral suite. Sorting, fair. Massive spheroidal weathering. Weathers to yellowish gray (5*Y* 7/2)	18+	0
82. Sandstone, massive, slabby, arkosic, calcareous, mixture of very fine grained sand and pods or lenses of silt (definite brackish-water deposit), yellowish-gray (5*Y* 7/2). Mottled where silt is concentrated. Weathers to grayish yellow (5*Y* 8/4). Many worm tubes or pelecypod burrowings (some 12 in. long)	15	0
81. Siltstone, thick-bedded, mottled, yellowish-gray (5*Y* 7/2), sandy. Brackish-water deposit. Weathers to grayish yellow (5*Y* 8/4)	2	0

SECTION 1.—*Eagle Sandstone on north side of Miner Creek in NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.*—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	Ft	in.
80. Sandstone, thick-bedded, indurated, very fine grained, arkosic, very calcareous, light-olive-gray (5*Y* 6/1). Weathers to yellowish gray (5*Y* 7/2). Contains heavy-mineral suite	3	0
79. Sandstone, massive, poorly consolidated, light-greenish-gray (5*GY* 8/1), fine-grained to very fine grained, arkosic. Very poorly exposed. Weathers to yellowish gray (5*Y* 7/2)	4	0
78. Sandstone, massive, indurated, fine-grained, calcareous, light-gray (*N*7), arkosic. Weathers to yellowish gray (5*Y* 7/2). Contains heavy-mineral suite. Vertical worm tubes. Little banding along indistinct bedding planes noted in middle of unit	5	0
77. Sandstone, thick-bedded, fine-grained, poorly indurated, very light gray (*N*8), arkosic. Weathers to yellowish gray (5*Y* 8/1)	2	0
76. Sandstone, massive, fine-grained, light-olive-gray (5*Y* 6/1), indurated, calcareous, arkosic. Weathers to light brown (5*YR* 6/4). Conspicuously jointed N. 75°–85° W. normal to base of bed. Lower 1–2 ft shows faint, indistinct bedding. A few worm tubes(?) associated with irregular lenses and pods of poorly sorted mottled sandy siltstone	12	0
75. Sandstone and siltstone, thin-bedded, light-olive-gray (5*Y* 6/1), arkosic, indurated, calcareous (very calcareous in lower half), very fine grained; weathers to yellowish gray (5*Y* 7/2). Contains heavy-mineral suite	2	0

	in.
Siltstone	4
Sandstone	7
Siltstone	2
Sandstone	7
Siltstone	4

	Ft	in.
74. Sandstone, indurated, very fine gained, light-gray (*N*7), arkosic, very calcareous. Weathers to yellowish gray (5*Y* 7/2). Contains heavy-mineral suite. Sorting, fair. Attitude N. 75° W., 39° NE	1	0
73. Siltstone, light-olive-gray (5*Y* 6/1), calcareous. Weathers to yellowish gray (5*Y* 7/2)		6
72. Sandstone, platy, light-gray (*N*7), arkosic, fine-grained, calcareous. Weathers to yellowish-gray (5*Y* 7/2) thin sheets (½ in. or less thick). Contains a heavy-mineral suite that is banded along many bedding planes like varves	6	0
71. Sandstone, medium-bedded, very fine grained, light-olive-gray (5*Y* 6/1), silty, poorly sorted, carbonaceous, arkosic, slightly calcareous; contains calcareous lenses 1 ft thick. Weathers to yellowish		

SECTION 1.—*Eagle Sandstone on north side of Miner Creek in NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.*—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	Ft	in.
gray (5*Y* 7/2). Contains macerated plant fragments and heavy minerals	1	6
70. Sandstone, massive, very fine grained, light-olive-gray (5*Y* 6/1), arkosic, very calcareous. Weathers to yellowish gray (5*Y* 7/2). Contains a few plant fragments and heavy minerals. Poorly developed spheroidal weathering	5	0
69. Siltstone, platy (⅛ in. or less), olive-gray (5*Y* 4/1), slightly carbonaceous, very calcareous. Weathers to yellowish gray (5*Y* 7/2)	1	0
68. Sandstone, platy, very fine grained, light-olive-gray (5*Y* 6/1), arkosic, very calcareous, indurated. Weathers to light olive gray (5*Y* 5/2). Contains heavy-mineral suite	2	0
67. Siltstone, very carbonaceous		3
66. Sandstone, massive, poorly indurated (except for very calcareous pods and lenses), poorly sorted, silty, very fine grained, arkosic, pale-olive (10*Y* 6/2); contains very calcareous pods and lenses. In places, mottled by concentration of silt. Typical of brackish-shallow-water deposit. Contains plant fragments and heavy minerals	5+	0
65. Concealed; probably thin-bedded very fine grained arkosic sandstone. Considerable sandstone float for this interval	6	0
64. Sandstone, thin-bedded, light-olive-gray (5*Y* 6/1), fine-grained, arkosic, calcareous. Bedding $<$¼ in. thick, marked by bands of heavy minerals. Weathers to yellowish-gray (5*Y* 7/2) ½–2-in. slabs. Contains disseminated plant fragments. Attitude N. 84° W., 41° NE	2	0
63. Sandstone, thin-bedded, silty, very fine grained, arkosic, calcareous, light-olive-gray (5*Y* 6/1). Weathers to yellowish gray (5*Y* 7/2). Less indurated than overlying sandstone. Base not exposed	4+	0
62. Concealed; probably thin-bedded silty very fine grained sandstone	23	0
61. Sandstone, thin-bedded, light-olive-gray (5*Y* 6/1), indurated (slight ridge former), very fine grained, calcareous. Weathers to yellowish-gray (5*Y* 6/2) slabs ½–2 in. thick. Contains plant fragments and heavy-mineral suite	2+	0
60. Concealed; probably thin-bedded silty very fine grained sandstone	12	0
59. Sandstone, platy, light-olive-gray (5*Y* 6/1), calcareous, arkosic, very fine grained. Weathers to slabs about ½ in. thick. Contains heavy-mineral suite and plant fragments—one fair quality leaf impression noted. Attitude N. 89° W., 42° NE	4	0
58. Concealed; probably thin-bedded silty very fine grained sandstone	4	0

SECTION 1.—*Eagle Sandstone on north side of Miner Creek in NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.*—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	Ft	in.
57. Sandstone, platy, light-olive-gray (5*Y* 6/1), calcareous, arkosic, very fine grained. Weathers to slabs about ½ in. thick. Contains heavy-mineral suite and plant fragments	4	0
56. Concealed; probably thin-bedded silty very fine grained sandstone	8	0
55. Sandstone, platy, indurated (slight ridge former), calcareous, arkosic, very fine grained, light-olive-gray (5*Y* 6/1). Angular to subangular grains. Sorting, fair. Crossbedded. Weathers to yellowish gray (5*Y* 7/2). Few poorly preserved leaf impressions. Calcite veinlets <¼ in. thick along fracture surfaces	2	0
54. Concealed; probably thin-bedded silty very fine grained sandstone	20	0
53. Sandstone, platy, indurated (slight ridge former), calcareous, arkosic, very fine grained, light-olive-gray (5*Y* 6/1). Angular to subangular grains. Sorting, fair. Crossbedded. Weathers to yellowish gray (5*Y* 7/2)	3	0
52. Concealed; probably thin-bedded silty very fine grained sandstone	8	0
51. Sandstone, platy, indurated, calcareous, arkosic, very fine grained, light-olive-gray (5*Y* 6/1). Weathers to yellowish gray (5*Y* 7/2). Attitude N. 83° W., 49° NE	3	0
50. Concealed; probably thin-bedded silty very fine grained sandstone	17	0
49. Sandstone, platy, indurated (slight ridge former), calcareous, arkosic, very fine grained, light-olive-gray (5*Y* 6/1). Angular to subangular grains. Sorting, fair. Crossbedded. Weathers to yellowish gray (5*Y* 7/2)	3	0
48. Concealed; probably thin-bedded silty very fine grained sandstone	12	0
47. Sandstone, platy, indurated (slight ridge former), calcareous, arkosic, very fine grained, light-olive-gray (5*Y* 6/1). Angular to subangular grains. Sorting, fair. Crossbedded. Weathers to yellowish gray (5*Y* 7/2)	2	0
46. Concealed; probably thin-bedded silty very fine grained sandstone	4	0
45. Sandstone, platy, indurated (slight ridge former), calcareous, arkosic, very fine grained, light-olive-gray (5*Y* 6/1). Angular to subangular grains. Sorting, fair. Crossbedded. Weathers to yellowish gray (5*Y* 7/2). Large very calcareous olive-gray (5*Y* 5/1) concretionary lenses of sandstone (some as large as 2×5 ft). They weather to yellowish gray (5*Y* 6/2) with pronounced spheroidal weathering	5 4	0
44. Sandstone, platy, slightly indurated, arkosic, calcareous, very fine grained, light-olive-gray (5*Y* 6/1); interbedded thin-bedded silty very fine grained sandstone. Weathers to yellowish gray (5*Y* 6/2)	14	0

SECTION 1.—*Eagle Sandstone on north side of Miner Creek in NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.*—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	Ft	in.
43. Sandstone, thin- to medium-bedded, indurated (slight ridge former), calcerous, very fine grained, arkosic, light-olive-gray (5*Y* 6/1). Angular to subangular grains. Sorting, fair. Weathers to yellowish gray (5*Y* 6/2)	2	6
42. Sandstone, thin-bedded, silty, very fine grained, light-olive-gray (5Y 6/1). Weathers to yellowish gray (5*Y* 6/1). Poorly exposed	2	6
41. Tuff, microlitic, medium-bedded, medium-dark-gray (*N*4), indurated, silty, very fine grained, calcareous (few small secondary calcite crystals), andesitic. Angular grains. Poorly sorted. Weathers to olive gray (5*Y* 3/1). Rock composed mostly of volcanic rock fragments and plagioclase (andesine). Many vugs <1/4 in. in diameter. Attitude N. 68° W., 38° NE	1	0
40. Sandstone, thick-bedded, dark-greenish-gray (5*GY* 4/1), poorly sorted, silty, medium-grained, angular grains, slightly calcareous, andesitic. Composed of volcanic rock fragments and plagioclase. Weathers to greenish gray (5*GY* 6/1). Faint, poorly formed bedding. Poorly sorted	3	0
39. Siltstone, massive, tuffaceous, light-olive-gray (5*Y* 5/2). Contains disseminated plant fragments. Weathers to yellowish gray (5*Y* 7/2)	4	0
Possible fault of less than a few feet displacement.		
38. Tuff, microlitic, massive, calcareous, medium-light-gray (*N*6), indurated, very fine grained, andesitic. Angular grains. Poorly sorted. Breaks with conchoidal fracture. Composed of volcanic rock fragments and plagioclase (too altered for composition determination). Weathers to dark yellowish brown (10*YR* 4/2). Many small vugs—some coated first with calcite and later with silica	4	0
37. Coal (Middle coal bed or locally the Cokedale No. 3 bed)	1	0
in.		
Coal — 5		
Siltstone, carbonaceous — 1		
Bone — 2		
Siltstone, very carbonaceous — 2		
Siltstone, carbonaceous — 2		
36. Sandstone, indurated, thin- to medium-bedded, fine-grained, slightly arkosic, yellowish-gray (5*Y* 7/2). Contains heavy-mineral suite. Weathers to yellowish brown (10*YR* 5/2)	1	0
35. Siltstone, poorly exposed, carbonaceous	3	0
34. Sandstone, thin-bedded to massive, yellowish-gray (5*Y* 7/2), slightly arkosic, very fine grained, very calcareous. Weathers to yellowish gray (5*Y* 6/2)	12	0

SECTION 1.—*Eagle Sandstone on north side of Miner Creek in NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.*—Continued

Eagle Sandstone (Upper Cretaceous)—Continued		Ft	in.
33. Siltstone, platy, greenish-gray (5*GY* 6/1), sandy. Contains disseminated plant fragments. Weathers to yellowish gray (5*Y* 8/1)		7	0
32. Coal (Maxey coal bed or locally the Cokedale No. 2 bed)		6	0
Siltstone, very carbonaceous, with coaly streaks (almost bone)	Ft 1		
Siltstone, very carbonaceous, approaches character of coal bed. Many tuffaceous siltstone partings	5		
31. Sandstone, platy, carbonaceous, light-olive-gray (5*Y* 5/1), very calcareous, silty, very fine grained, arkosic. Weathers to grayish-yellow (5*Y* 7/4) slabs ½–2 in. thick. Few plant fragments. Attitude N. 89° W., 35° NE		5	0
30. Sandstone, very massive (cliff former directly opposite Miner Creek junction), light-gray (*N*7), fine-grained, crossbedded, arkosic. Good heavy-mineral suite. Calcareous. Massive spheroidal weathering. Weathers to grayish yellow (5*Y* 7/4). Unit lenses out eastward and westward and does not occur behind the coke ovens. Large plant fragments (some several feet across) and several beds of oysters near middle of unit on east side. Many intraformational breccias about 1–2 ft thick		42	0
29. Siltstone, platy, carbonaceous, sandy; calcareous concretions <3 in. diameter, dark yellowish brown (10*YR* 4/2), moderate yellowish brown (10*YR* 5/4). Carbonized plant fragments. Poorly exposed. Immediately east of section this unit becomes very carbonaceous (almost characteristic of coal bed)		2	0
28. Sandstone, massive to thin-bedded, light-olive-gray (5*Y* 6/1), very fine grained, indurated, calcareous, slightly carbonaceous. Contains heavy-mineral suite. In places, resembles brackish-water deposition. Weathers to yellowish gray (5*Y* 8/1). Unit thins abruptly eastward. Contains leaf impressions. A few vertical worm tubes		18	0
27. Siltstone, massive, greenish-gray (5*GY* 6/1); poorly exposed		5	0
26. Siltstone, very carbonaceous, with coaly streaks		1	0
25. Siltstone, massive, dark-greenish-gray (5*GY* 4/1). Contains disseminated plant fragments. Limonitic concretions noted. Weathers to light olive gray (5*Y* 6/1)		5	7
24. Siltstone, bone, and streaks of coal, very carbonaceous. Many carbonaceous, tuffaceous, sandy siltstone partings (as much as 3 in. thick, generally <2 in.). Just east of section the unit is cut out by a fault. Behind the coke ovens this unit is approximately the same thickness. Much of the adjustment during the orogeny of folding and thrusting was taken up in the coal and siltstone beds, which display considerable shearing and many tight folds that do not occur in overlying and underlying resistant sandstones. There are undoubtedly many bedding-plane faults as indicated by bedding-plane shears. Many partings now have a boudinagelike structure. Some carbonaceous siltstone beds contain macerated plant fragments. This unit correlates with the Big Dirty coal bed or, locally, the Cokedale No. 1 bed		46	0
Total Eagle Sandstone above Virgelle Member		535	0
Virgelle Sandstone Member:			
23. Sandstone, massive, indurated (cliff former), generally noncalcareous, very light gray (*N*8), fine-grained, arkosic. Although very massive, bedding can be delineated by dark ⅛–1/16-in. bands of heavy minerals. Unit is almost entirely crossbedded. Crossbedding is generally 2–3 ft long, or less, and generally truncated. Massive spheroidal weathering. Weathers to yellowish gray (5*Y* 7/2). Contains a few channel-fill deposits of pebbles and cobbles of siltstone		25	6
22. Sandstone, medium-bedded, fine-grained, light-olive-gray (5*Y* 5/2), calcareous, arkosic. Weathers to moderate yellowish brown (10*YR* 5/4)		1	0
21. Sandstone, medium-bedded, very poorly sorted, olive-gray (5*Y* 4/1), fine- to medium-grained, noncalcareous; derived from volcanic rock. Bottom 5 in. is olive-black (5*Y* 2/1) tuffaceous siltstone. Entire unit contains many small channel-fill deposits of silt and sand		1	0
20. Sandstone, massive, generally noncalcareous, very light gray (*N*8), fine-grained, arkosic. Less indurated than overlying units		4	0
19. Sandstone, massive, indurated, generally noncalcareous, very light gray (*N*8), fine-grained, arkosic. Siltstone-pebble conglomerate generally at base		8	0
18. Sandstone, thin-bedded (½–4 in. thick), indurated, calcareous, greenish-gray (5*GY* 6/1), very fine grained, arkosic. Weathers to olive gray (5*Y* 4/1). Has 2-in. siltstone both in middle and at base of unit		1	6
17. Sandstone, medium-bedded, calcareous, very light gray (*N*8), fine- to medium-grained, arkosic. Contains abundant heavy-mineral suite. Many small channel-fill deposits of siltstone pebbles. Bed is irregular in thickness and generally crossbedded.			

SECTION 1.—*Eagle Sandstone on north side of Miner Creek in NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.*—Continued

	Ft	in.
Eagle Sandstone (Upper Cretaceous)—Continued		
Angular to subrounded grains. Sorting, fair. Weathers to yellowish gray (5*Y* 7/2)	1	0
16. Sandstone, medium-bedded, indurated, calcareous, greenish-gray (5*GY* 6/1), very fine grained, arkosic. Weathers to olive gray (5*Y* 4/1)	1	0
15. Sandstone, medium-bedded, very light gray, fine-grained, arkosic. Contains calcareous pods or lenses. Crossbedded. A few plant fragments. Contains heavy-mineral suite. Poorly sorted; some small channel-fill deposits of coarse-grained sandstone	2	0
14. Sandstone, poorly sorted, very fine grained, dark-greenish-gray (5*GY* 4/1), noncalcareous, andesitic. Crossbedded. Weathers to light olive gray (5*Y* 5/2)	1	0
13. Siltstone, thin-bedded, olive-gray (5*Y* 4/1). Weathers to light olive gray (5*Y* 5/2). Contains disseminated plant fragments		6
12. Sandstone, massive, very poorly sorted, coarse-grained, pale-olive (10*Y* 6/2) Weathers to yellowish gray (5*Y* 7/2). Contains sporadic pebbles of siltstone. Contains 4-in. olive-gray siltstone bed in middle of unit	4	0
11. Sandstone, medium-bedded, indurated, calcareous, fine-grained, pale-olive (10*Y* 6/2). Weathers to yellowish gray (5*Y* 7/2)	1	0
10. Sandstone, thick-bedded, very light gray, fine-grained, arkosic	3	0
9. Transition to overlying sandstone	1	0
8. Sandstone, indurated, olive-gray (5*Y* 4/1), very fine grained, andesitic. Weathers to dark yellowish brown (10*YR* 4/2). Noncalcareous		6
7. Transition from underlying sandstone	1	0
6. Sandstone, massive, very light gray, fine-grained, arkosic	4	0
5. Sandstone, medium-bedded, poorly sorted, very fine grained, andesitic, dusky-yellow-green (5*GY* 5/2). Weathers to moderate yellowish brown (10*YR* 5/4)	1	0
4. Sandstone, medium-bedded, poorly sorted, medium- to coarse-grained, very light gray (*N*8), arkosic, crossbedded. Weathers to yellowish gray (5*Y* 7/2)	1	0
3. Sandstone, medium-bedded, very light gray, fine-grained, arkosic	1	0
2. Sandstone, platy, very light gray (*N*8), indurated, calcareous, fine-grained, arkosic, with thin (2 in. or less) stringers of coarse-grained sandstone. Crossbedded in part. Weathers to olive gray (5*Y* 4/1)	2	0
1. Sandstone, massive, very light gray (*N*8), fine-grained, arkosic, slightly calcareous, crossbedded. Contains quartz, orthoclase, andesine, heavy minerals, and fragments of andesite. Contains many vertical worm(?) tubes. Cliff-former. 4-ft zone of very poorly sorted sandstone containing silt that gives rock a mottled appearance 4 ft from top of unit. Massive spheroidal weathering. Angular to subrounded grains. Sorting, fair. Weathers to yellowish gray (5*Y* 7/2)	44	0
Total thickness of Virgelle Sandstone Member	110	0
Total thickness of Eagle Sandstone	645	0
Telegraph Creek Formation.		

SECTION 2.—*Eagle Sandstone measured on west side of the Yellowstone River, NE¼ sec. 27, T. 2 S., R. 9 E., and adjusted with Deerfield Oil Corp. Strong well 1, SW¼ sec. 11, T. 2. S., R. 9 E., Park County, Mont.*

[Measured by Albert E. Roberts in 1961]

	Ft	in.
Cokedale Formation (Upper Cretaceous)		
Eagle Sandstone (Upper Cretaceous):		
28. Sandstone, medium-bedded, feldspathic, micaceous, fine- to medium-grained, light-olive-gray; rounded to subrounded grains; contains heavy-mineral suite and chert grains	2	0
27. Siltstone, thin- to medium-bedded, carbonaceous, olive-gray; thin interbedded coal beds (correlates with Cokedale coal bed)	8	0
26. Sandstone, medium- to thick-bedded, calcareous, micaceous, volcanic rock fragments, dusky-yellow-green; transition of Eagle Sandstone and Livingston Group lithologies; angular grains. Thin coal bed near middle of unit (correlates with Paddy Miles coal bed)	24	0
25. Shale, massive, silty, pyritic, pale-olive	20	0
24. Sandstone, thick-bedded, calcareous, very fine grained to fine-grained, yellow-green; angular grains	16	0
23. Siltstone, thin-bedded, olive-gray; thin interbedded olive-gray shale	45	0
22. Shale, thin-bedded, sandy, carbonaceous, gray; contains abundant orange (heulandite(?)) specks	10	0
21. Sandstone, medium-bedded, calcareous, micaceous, pyritic, medium- to coarse-grained, very light gray; contains heavy-mineral suite	8	0
20. Shale, massive, silty, pyritic, olive-gray	22	0
19. Sandstone, medium-bedded, silty, calcareous, micaceous, very fine grained, light-gray; contains heavy-mineral suite	10	0
18. Shale, massive, sandy, olive-gray; contains abundant orange (heulandite(?)) specks; thin interbedded olive-gray siltstone	18	0
17. Sandstone, thick-bedded, calcareous, micaceous, medium- to coarse-grained, very light gray; contains heavy-mineral suite	27	0

SECTION 2.—*Eagle Sandstone measured on west side of the Yellowstone River, NE¼ sec. 27, T. 2 S., R. 9 E., and adjusted with Deerfield Oil Corp. Strong well 1, SW¼ sec. 11, T. 2 S., R. 9 E., Park County, Mont.*—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	Ft	in.
16. Sandstone, thin- to medium-bedded, silty, calcareous, micaceous, very fine grained to fine-grained, very light gray; contains heavy-mineral suite	10	0
15. Sandstone, thin-bedded, silty, calcareous, micaceous, very fine grained to medium-grained, light-olive-gray; thin interbedded siltstone and shale	30	0
14. Sandstone, thick-bedded, calcareous, micaceous, pyritic, fine- to coarse-grained, light-gray; contains orange (heulandite(?)) specks; contains heavy-mineral suite; angular grains	32	0
13. Sandstone, thin-bedded, silty, calcareous, very fine grained to fine-grained, light-olive-gray; thin interbedded siltstone and shale	18	0
12. Sandstone, thick-bedded, calcareous, micaceous, very fine grained to fine-grained, light-olive-gray; thin interbedded siltstone	25	0
11. Shale, massive, sandy, pyritic, light-gray; contains orange (heulandite(?)) specks and thin interbedded siltstone	27	0
10. Siltstone, thin-bedded, sandy, micaceous, medium-dark-gray; thin interbedded shale	8	0
9. Shale, massive, silty, micaceous, olive-gray	15	0
8. Sandstone, thick-bedded, calcareous, very fine grained to coarse-grained, light-gray; predominantly quartz grains; rounded to subangular grains	32	0
7. Sandstone, thin-bedded, silty, calcareous, very fine grained to fine-grained, light-gray; contains orange (heulandite(?)) specks	8	0
6. Shale, massive, sandy, pyritic, medium-gray to olive-gray with orange (heulandite(?)) specks	36	0
5. Sandstone, massive, arkosic, medium- to coarse-grained, light-olive-gray (5*Y* 6/1); interbedded silty very fine grained sandstone and carbonaceous siltstone in the lower 10 ft	28	0
4. Coal (Big Dirty coal bed—measured at caved portal of Williams mine)	17	0

	In.
Bone	1
Coal	26
Bony coal	4
Siltstone, carbonaceous, sandy	3
Siltstone, very carbonaceous	3
Coal	2
Sandstone, fine-grained, arkosic	2
Siltstone, carbonaceous	12
Coal	5
Bone	1
Coal	1
Siltstone, carbonaceous	12
Sandstone, fine-grained, arkosic	9
Siltstone, very carbonaceous	3
Coal	21
Sandstone, very fine grained	2
Coal	2
Siltstone, very carbonaceous; stringers of coal	16
Sandstone, very fine grained, arkosic	10
Bone	3
Sandstone, very fine grained	2
Siltstone, carbonaceous	4
Coal	20
Siltstone, carbonaceous	3
Coal	1
Sandstone, very fine grained	3
Bone	4
Bony coal	10
Coal	4
Siltstone, very carbonaceous	15

	Ft	in.
Total Eagle Sandstone above Virgelle Member	496	0
Virgelle Sandstone Member:		
3. Sandstone, massive, indurated, calcareous, light-gray (*N*7), fine- to medium-grained, arkosic; weathers to grayish yellow (5*Y* 7/4)	62	0
2. Siltstone, micaceous, carbonaceous; interbedded fine- to medium-grained sandstone	27	0
1. Sandstone, massive, indurated, light-gray (*N*7), fine-grained, arkosic. Contains heavy-mineral suite. Weathers to yellowish gray (5*Y* 7/2)	28	0
Total thickness of Virgelle Sandstone Member	117	0
Total thickness of Eagle Sandstone	613	0

Telegraph Creek Formation.

AGE AND CORRELATION

Fossil leaves that were collected by members of the Northern Transcontinental Survey from beds presumably in the lower part of the Livingston Group were described by Lesquereux (1873, p. 404–417) and assigned to the early Eocene. Knowlton (1892) examined this and subsequent collections from other localities in this area, including some from the Eagle Sandstone, and designated the entire collection as the fossil flora of the Bozeman coal field of Laramie (Late Cretaceous) age. According to Pumpelly (1886, p. 692), the coal-bearing horizon at the Bozeman coal field was "about 3,700 feet above the Jurassic and some distance above fossils of Benton or Niobrara age and yet so low in the Cretaceous column as to be apparently below the Laramie." Davis (1886, p. 698) stated that "the horizon of workable coals near the Muir tunnel, east of Bozeman, [Bozeman Pass, 5 miles west of Cokedale] is without question lower than the Laramie formation to which the lignitic coals of the Rocky Mountain region have generally been referred." However, Weed (1893, p. 18) again assigned the coal-bearing formation at Livingston to the Laramie Formation, partly on the basis of Knowlton's work and partly because of the conformable relation with underlying rocks (Telegraph Creek Formation) which he believed to be of Montana age. The basal massive sandstone (Virgelle Sandstone Member of the Eagle Sandstone) was assigned by Weed (1893, p. 19) to the Fox Hills Sandstone. The Laramie Formation, according to Weed (1893, p. 34), was overlain unconformably by his Livingston Formation. T. W. Stanton (in Stone and Calvert, 1910, p. 659–660) identified marine fossils of early Montana age from beds at the base of the coal-bearing formation east of the Bridger Range and correlated the formation in that area with the Eagle Sandstone in the northern part of the Crazy Mountains basin, where the Eagle had been established by Stone (1909, p. 78).

The first comprehensive study of a megafauna from the Eagle Sandstone and related formations in the western interior of the United States was made by Reeside (1927). Collections from localities north of Livingston containing a marine fauna were assigned to the lower part of the Montana Group of the Upper Cretaceous (Reeside, 1927, p. 1).

The Eagle Sandstone in the Livingston coal field contains a few sporadic poorly preserved *Inoceramus* sp. and *Ostrea* sp. To the north, in SE¼ sec. 24, T. 4 N., R. 7 E., J. R. Gill and the author collected *Inoceramus* sp., *Ostrea* sp., *Crassatella* sp., and *Tellina* sp. from the Eagle Sandstone. G. D. Fraser (written commun., 1961) collected the following fossils, which were identified by W. A. Cobban, from the upper part of the Eagle near Gardiner, Mont., 0.9 mile east-southeast of the mouth of the Gardiner River on the south bank of the Yellowstone River: *Inoceramus* sp., *Ostrea coalvillensis* Meek, and *Cymbophora arenaria* (Meek)?. According to Cobban (written commun., 1961), this fauna indicates that the top of the Eagle Sandstone at Gardiner is no younger than the lower part of the Eagle of central Montana and that even an older age is possible. The Eagle Sandstone in the Livingston coal field is considered by the author to be the same age as the Eagle at Gardiner, as the two localities are on the depositional strike of the formation. Correlation and stratigraphic relations of the Eagle Sandstone of the Livingston area with rocks of other areas in Montana and Wyoming are shown in figure 5.

COAL DEPOSITS IN THE EAGLE SANDSTONE

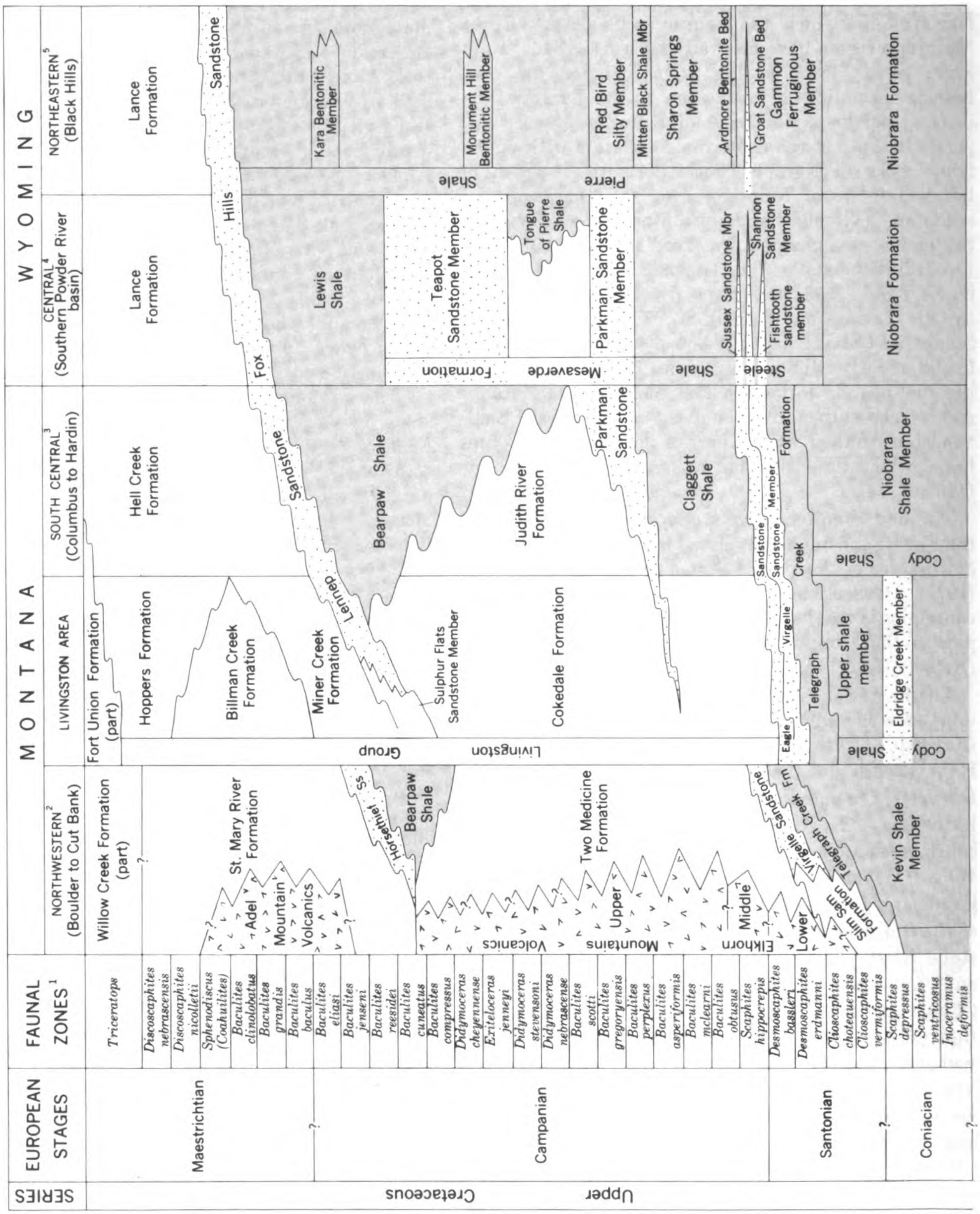
The Livingston coal field is a T-shaped approximately 35-square-mile area between Livingston and Bozeman. The coal field was formerly much larger than at present; however, uplift and folding accompanied by erosion in the northern part of the Gallatin Range has left comparatively small segments of coal-bearing rocks—generally in a narrow belt along the flanks of the large anticlines and in the narrow troughs of the synclines (pl. 1). Considerable faulting and folding took place during this interval of Late Cretaceous and early Tertiary orogeny. Few coal beds dip less than 30°, and most dip much more; in several localities the beds are overturned. As a result of the faulting and folding, much crushing of the coal took place; hence, in each mine the large amount of slack was a serious drawback for marketing the coal.

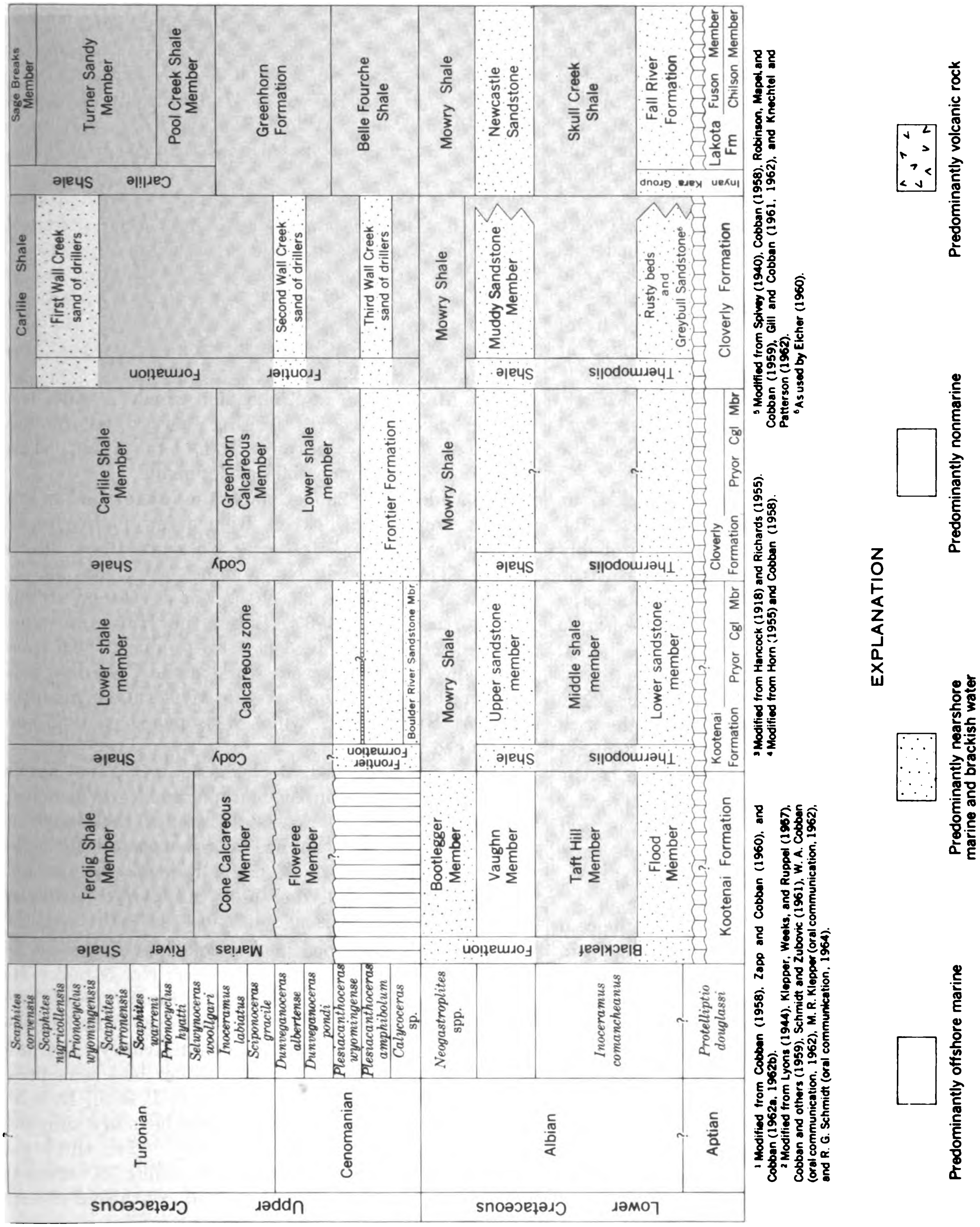
Coal was originally widespread in the Eagle Sandstone in southwestern Montana. Coal beds in the Eagle were mined or prospected from Livingston eastward to the Albertson mine, near Dean (Calvert, 1916, p. 207); northward to the Musselshell River, near Shawmut (Stone, 1909, p. 81–87); and southward to the Electric coal field, near Gardiner (Calvert, 1912b).

Coal beds were most extensively developed near Livingston and south to the Electric coal field. East of Livingston the coal beds in the Eagle Sandstone that were exposed in many prospects indicate that the beds become thinner and have more clastic partings. No large producing mines were developed there (Calvert, 1916; Richards, 1957, p. 418). North of Livingston, in the western part of the Crazy Mountains basin, considerable prospecting took place, but no producing mines were developed (Stone, 1909). The coal beds are thinner, have more partings, and have been broken and crushed by folding and faulting. The existence of quality coal in commercial quantities seems very unlikely in this area.

STRATIGRAPHIC POSITION AND CHARACTER OF COAL BEDS

Most coal beds in the Livingston coal field occur in two well-defined zones, designated the upper and lower coal zones (Roberts, 1957, p. 42). These zones represent coal-bearing coastal-swamp deposits laid down during regressive stages of the Eagle sea in much of southwestern Montana. These two zones are more persistent than any of the individual coal beds. The thickness of individual beds ranges from a few inches to more than 10 feet, but it averages 3–4 feet. Coal-bed outcrops and zones and localities measured and sampled are indicated on plate 1. These measured sections, arranged stratigraphically, are shown on plates 3 and 4. The coal beds in these zones are intercalated with carbonaceous shale, siltstone, and sand-


SERIES
Upper Cretaceous
EUROPEAN STAGES
Maestrichtian
Campanian
Santonian
Coniacian
FAUNAL ZONES[1]
Triceratops
Discoscaphites nebrascensis
Discoscaphites nicolletii
Sphenodiscus (Coahuilites)
Baculites clinolobatus
Baculites grandis
Baculites baculus
Baculites eliasi
Baculites jenseni
Baculites reesidei
Baculites cuneatus
Baculites compressus
Didymoceras cheyennense
Exiteloceras jenneyi
Didymoceras stevensoni
Didymoceras nebrascense
Baculites scotti
Baculites gregoryensis
Baculites perplexus
Baculites asperiformis
Baculites mclearni
Baculites obtusus
Scaphites hippocrepis
Desmoscaphites bassleri
Desmoscaphites erdmanni
Clioscaphites choteauensis
Clioscaphites vermiformis
Scaphites depressus
Scaphites ventricosus
Inoceramus deformis
M O N T A N A
NORTHWESTERN[2] (Boulder to Cut Bank)
Willow Creek Formation (part)
St. Mary River Formation
Adel Mountain Volcanics
Horsethief Ss
Bearpaw Shale
Two Medicine Formation
Elkhorn Mountains Volcanics
Upper
Middle
Lower
Virgelle Sandstone
Telegraph Creek Formation
Slim Sam Formation
Kevin Shale Member
LIVINGSTON AREA
Fort Union Formation (part)
Hoppers Formation
Billman Creek Formation
Miner Creek Formation
Sulphur Flats Sandstone Member
Cokedale Formation
Livingston Group
Eagle Sandstone
Virgelle Sandstone
Telegraph Creek Formation
Upper shale member
Eldridge Creek Member
Cody Shale
SOUTH CENTRAL[3] (Columbus to Hardin)
Hell Creek Formation
Lennep Sandstone
Bearpaw Shale
Judith River Formation
Parkman Sandstone
Claggett Shale
Eagle Sandstone
Virgelle Sandstone Member
Telegraph Creek Formation
Niobrara Shale Member
Cody Shale
W Y O M I N G
CENTRAL[4] (Southern Powder River basin)
Lance Formation
Fox Hills Sandstone
Lewis Shale
Teapot Sandstone Member
Tongue of Pierre Shale
Parkman Sandstone Member
Mesaverde Formation
Sussex Sandstone Mbr
Shannon Sandstone Member
Fishtooth sandstone member
Steele Shale
Niobrara Formation
NORTHEASTERN[5] (Black Hills)
Lance Formation
Sandstone
Kara Bentonitic Member
Monument Hill Bentonitic Member
Red Bird Silty Member
Mitten Black Shale Mbr
Sharon Springs Member
Ardmore Bentonite Bed
Groat Sandstone Bed
Gammon Ferruginous Member
Pierre Shale
Niobrara Formation



[1] Modified from Cobban (1958), Zapp and Cobban (1960), and Cobban (1962a, 1962b).
[2] Modified from Lyons (1944), Klepper, Weeks, and Ruppel (1957), Cobban and others (1959), Schmidt and Zubovic (1961), W. A. Cobban (oral communication, 1962), M. R. Klepper (oral communication, 1962), and R. G. Schmidt (oral communication, 1964).
[3] Modified from Hancock (1918) and Richards (1955).
[4] Modified from Horn (1955) and Cobban (1958).
[5] Modified from Spivey (1940), Cobban (1958), Robinson, Mapel and Cobban (1959), Gill and Cobban (1961, 1962), and Knechtel and Patterson (1962).
[6] As used by Eicher (1960).

FIGURE 5.—Correlation and stratigraphic relations of Cretaceous rocks in the Livingston area and other areas in Montana and Wyoming.

stone; a band of coal at any one locality may change to bone and (or) carbonaceous shale within a short distance laterally. Correlation and lateral variations of the coal beds of the two zones throughout the coal field are also shown on plates 3 and 4. Coal-bed names are those used by the miners during mining operations. All the coal beds vary in thickness laterally (pl. 2); the frequent change in thickness is in part due to the original depositional character and in part due to postdepositional tectonic alteration.

The upper coal zone contains the Cokedale, Paddy Miles, Storrs No. 3, and one or more unnamed coal beds (pl. 2). Of these, the Cokedale is the thickest and of the best quality. It contains fewer partings, is more persistent over a wider area, and is generally of coking quality. This bed was extensively mined at Cokedale, Timberline, and Chestnut.

The lower coal zone contains the Middle, Maxey, Big Dirty, and four or more unnamed lenticular coal beds (pl. 2). Of these, the Maxey bed has been the largest producer.

In 1907 J. W. Groves collected samples from the Washoe Coal Co. No. 3 mine (Belden and others, 1909, p. 14). Their samples 166–D and 167–D were probably collected from the Cokedale bed, as is indicated by the distance from the portal to the location from which the two samples were collected; and the 40-ton run-of-mine sample must have been from the Storrs No. 3 bed, which was the main bed being mined at the time (pl. 5). The bed assignment is also supported by the large difference in British thermal units between the two mine samples and the run-of-mine sample (Belden and others, 1909, p. 15). Coal from the Cokedale bed is 100–200 Btu higher than that from the Storrs No. 3 bed in this district. The run-of-mine sample was used in three washing tests (table 3) and four coking tests (tables 4, 5).

COKEDALE DISTRICT

The Cokedale district lies along the strike of the coal beds on the northeast flank of the Canyon Mountain anticline in secs. 21–28, T. 2 S., R. 8 E., and secs. 27–30, T. 2 S., R. 9 E. Most mines in the district were developed near Cokedale along the drainages of Miner and Eldridge Creeks. The location and extent of the district, the location of the mines and measured coal sections, and the relative position of the coal beds and the general structure are shown on plate 1. The geology of the district was mapped in detail by Roberts (1964c, d). The area is accessible from U.S. Highway 10 by the Cokedale road, constructed on the abandoned grade of the Cokedale Branch of the Northern Pacific Railway Co.

The Eagle Sandstone in the Cokedale district contains six principal coal beds (fig. 4): the Cokedale bed (miners refer to it as the Cokedale or Cokedale No. 5); the Paddy Miles bed (referred to as the Cokedale No. 4); the Storrs No. 3, which was unnamed; the Middle bed (the Cokedale No. 3 or the Little bed); the Maxey bed (the Cokedale No. 2); and the Big Dirty bed (the Big Dirty or Cokedale No. 1). In the district the Cokedale, Paddy Miles, Middle, and Big Dirty beds were mined. Only the Cokedale was mined extensively, however.

The Big Dirty bed in this district is immediately above the Virgelle Sandstone Member and consists of carbonaceous shale and lenticular layers of impure coal, siltstone, and fine-grained sandstone. The bed ranges in thickness from 16 to 45 feet. It was prospected along its strike in secs. 27, 28, and 29, T. 2 S., R. 9 E.; however, the only known development was at the Williams mine (loc. 67, pl. 1).

The Maxey bed at Cokedale, which is 100 feet stratigraphically above the Big Dirty bed in this district, ranges in thickness from 1 to 2 feet. This bed has had no commercial development.

The Middle bed, 23 feet above the Maxey bed in this district, ranges in thickness from a few inches to 5½ feet and averages 3½ feet near Cokedale (locs. 28–30, pl. 3). The Cokedale No. 3 mine, SW¼ sec. 22, T. 2 S., R. 8 E. (near loc. 29, pl. 1), was developed on this bed in the early 1900's. Later, the Hubbard mine, SE¼ sec. 21, T. 2 S., R. 8 E., also produced coal from this bed. The most recent work in the Cokedale area was on the Middle bed at the McCormick prospect (loc. 28), SW¼ sec. 22, which was opened in 1955 and abandoned in 1956.

The Storrs No. 3 bed, at Cokedale, is 330 feet above the Middle bed and consists of upper and lower benches, each 2 feet thick, separated by 7 feet of carbonaceous siltstone. Although this bed was prospected throughout secs. 22–24 and 26, T. 2 S., R. 8 E., it was not developed commercially because it is thin and lenticular and has many partings.

The Paddy Miles bed in the Cokedale district is 26 feet stratigraphically above the Storrs No. 3 bed. Its thickness, which changes abruptly, ranges from 1 to 7 feet (locs. 27, 54, pl. 3). The bed was mined in the Cokedale No. 2 mines from the James entry, but production was small. The Paddy Miles bed was prospected throughout secs. 22–24 and 26, T. 2 S., R. 8 E., but no coal was produced because the beds are thin and lenticular and have many partings. In the lower workings of the Cokedale No. 1 mines, a crosscut revealed that the Paddy Miles bed contained coking coal, but the bed was too thin to be mined.

The Cokedale bed in this district is 11 feet above the Paddy Miles bed and is 2–9 feet thick. Throughout the northern part of the Livingston coal field, the

FIGURE 6.—Cokedale coal bed near main entry at Cokedale No. 1 mines in the Livingston coal field (loc. 54, pl. 1) showing general attitude and characteristic parting 1½ feet below top of the bed.

Cokedale bed contains a carbonaceous siltstone parting 1–2 feet below the top of the bed (fig. 6). At Cokedale the coal below this parting coked better than the coal above, and in places this upper bench was left in the roof. The Cokedale bed was the source of most coal and the only large source of coking coal mined in the district as well as in the entire Livingston coal field. The Cokedale Nos. 1 and 2, Sulphur Flats, Spangler, Kangley, Johnson, Buckskin, and the Northern Pacific Coal Co. mines all produced coal from this bed.

TIMBERLINE DISTRICT

West of the Cokedale district are mines and prospects of the Timberline district, in secs. 23–26, T. 2 S., R. 7 E., and secs. 30–32, T. 2 S., R. 8 E. (pl. 1). In contrast to the extensive faulting near the western part of the Cokedale district, the coal beds are tightly folded in the Eldridge Creek syncline. West of the syncline the coal beds encircle the northern plunge of the Center Hill anticline, and the Timberline mines and prospects are along the strike of the beds. Stratigraphy of the beds is shown on plate 3, and the geology of the district was mapped in detail by Roberts (1964e, h). Exploration in this district was concentrated on the Cokedale and Paddy Miles beds in the upper coal zone (pl. 2).

The Cokedale bed was the largest coal source in the Timberline district, and the Timberline No. 3 mine on this bed was one of the largest producers in the Livingston coal field. The bed is 4½–17 feet thick and generally contains many partings (locs. 11–75, pl. 3). The Cokedale and Paddy Miles beds united at one part of the workings in the Timberline No. 3 mine; this resulted in nearly 20 feet of good coal, which was called the Bonanza bed. All mines of the Timberline district were on the Cokedale bed.

The Paddy Miles bed is 3–4 feet thick and has a 2-foot-thick rider 4 feet above the main bed (pl. 3). The bed is thickest near Timberline. At the Timberline No. 3 mine and southward, the bed contains many partings. Near the Timberline No. 1 and Pendleton mines, the Paddy Miles bed contained 4 feet of good coal. Although this bed was proved commercial, it was not developed because of its proximity to the thicker Cokedale bed.

The Storrs No. 3 bed in this district, referred to by local miners as the Penman bed, is thin and impure and contains many partings. It was not developed commercially, although at the Timberline No. 3 mine it was 2 feet thick, including two partings (pl. 3, loc. 11).

Coal beds in the lower coal zone in the Timberline district are lenticular and contain many partings. Also, they crop out near the bottom of the valley and, therefore, are more costly to mine. Thus, there was little exploration and no development of these beds.

MEADOW CREEK DISTRICT

The Meadow Creek district, T. 2 S., R. 7 E., is west of the Timberline district and north of the Trail Creek district. The boundary between this district and the Timberline district in this study was established on the basis of difference in the directions of coal transportation. The boundary between the Meadow Creek and Trail Creek districts was near the drainage divide between the two creeks. Many mines and prospects of the Meadow Creek district are along or near the drainages of Meadow and Rocky Creeks. The location and extent of the district, the location of the mines and measured coal sections, the relative position of the coal beds, and the general structure are shown on plate 1. The geology of the district was mapped in detail by Roberts (1964e, f, h).

The Meadow Creek district flanks the south end of the Meadow Creek syncline and the north ends of the Storrs anticline, Goose Creek syncline, and Chestnut Mountain anticline. On the north end of Chestnut Mountain, the Meadow Creek district is bounded by a large fault that parallels the axis of the Kelly Canyon syncline. As a result of these folds and related minor folds and faults, structure of the district is complex.

The dip of the coal-bearing rocks throughout the district is steep—generally more than 45°—and in many places is nearly vertical. In the largest continuous underground workings (the Rocky Canyon mine), the dip of the coal ranged from 60° to 86° NE. and probably averaged about 80°.

Several diabase dikes intrude the coal-bearing rocks in this district. In sec. 28, T. 2 S., R. 7 E., a dike intruded along the axis of the Goose Creek syncline and formed a barrier between the mines on both flanks of the syncline. A dike in sec. 21, T. 2 S., R. 7 E., created areas of natural coke.

The six principal coal beds of the Eagle Sandstone are present in the Meadow Creek district (pl. 2), and all but the Middle bed have been extensively mined or prospected.

The Big Dirty bed ranges in thickness from 10 to 25 feet and consists of alternate bands of coal, bone, and carbonaceous shale. The only mines that produced coal from the Big Dirty bed were the Moran and the Washoe Coal Co. No. 4 (pl. 1). Several bands of coal in the Washoe Coal Co. No. 4 mine yielded coke of superior quality; however, they were too thin to be economic.

The Maxey bed is about 90 feet stratigraphically above the Big Dirty bed in this district. It is 2–8 feet thick in the southern part of the district but contains many partings; it thins northward, and near Chestnut it is less than 1 foot thick (pl. 2). The bed was worked in the Harrison, Monroe, and Planishek mines—all very small producers.

The Middle bed, 130 feet stratigraphically above the Maxey bed, consists of 3–10 feet of dirty coal and many partings. It was not commercially developed.

The unnamed bed at the base of the upper coal zone near Chestnut may correlate with the Bottamy bed in the Trail Creek district. This bed was prospected northwest of Chestnut but was not mined.

The Storrs No. 3 bed, 250 feet stratigraphically above the Middle bed in the Meadow Creek district, is 8–9½ feet thick, including 5–10 partings (locs. 7–39, pl. 4). The bed is thick and contains few partings near the community of Storrs; it was referred to as the Storrs No. 3 by the Washoe Coal Co. No. 3 miners. Other mines in the district that worked this bed were the Payne, Miller No. 1, Meadow Creek Nos. 2 and 3, Whitehead-Robinson, and Harris-Murphy (pls. 4, 5).

The Paddy Miles bed is 75–110 feet stratigraphically above the Storrs No. 3 bed in the Meadow Creek district. The bed generally is 3½–6 feet thick; however, in the crosscut driven from the north end of the workings on the Storrs No. 3 bed in the Washoe Coal Co. No. 3 mine (pl. 5), the bed where first encountered was 12 feet thick, of which 7–9 feet was coal. Extensive exploration to the north in this mine proved that such thickening was local. The Paddy Miles bed, in most places, has a parting near the middle composed of 2–6 inches of soft white sandstone interbedded with as much as 18 inches of coal and bone. The bed was extensively prospected in the vicinity of Storrs but was not mined.

The Cokedale bed in the Meadow Creek district is 0–95 feet stratigraphically above the Paddy Miles bed. The interval between these beds decreases northward, and at Chestnut the two unite (loc. 1, pl. 4). The Cokedale bed is 2½–18½ feet thick and contains several clastic partings and layers of bone. Northwest of the Chestnut mine the thickness of the bed decreases, and the number and thickness of clastic partings increase. North of the Bailey and Beadle mine, the bed seems to be merely a carbonaceous zone. The Cokedale bed was the source of most of the coal mined in the district. The Rocky Canyon (Chestnut), Mountain Side, Maxey, Bailey and Beadle, Hodson, Miller No. 2, Meadow Creek No. 1, and Lasich mines all produced coal from this bed.

TRAIL CREEK DISTRICT

The Trail Creek district joins the Meadow Creek district to the south and includes parts of Tps. 3 and 4 S., R. 8 E. In the northern part of the district, the coal-bearing Eagle Sandstone is confined to the trough of the Trail Creek syncline; in the southern part the coal-bearing rocks crop out southeastward, then westward, around the foothills to the Pine Creek syncline. The location and extent of the district, the location of the mines and measured coal sections, and the relative positions of the coal beds and faults are shown on plate 1. The geology of the district was mapped in detail by Roberts (1964b, e).

Center Hill, Pine Mountain, and the Hogback flank the district on the northeast. They form a high narrow range composed predominantly of upper Paleozoic rocks. A lesser range, composed mostly of Cretaceous and lower Tertiary rocks, lies to the south.

The structure of the Trail Creek district is complex and, because much of the coal-bearing strata is concealed and the mines and prospects are caved, many of the fault locations can only be approximated. Eldridge (1886, p. 748) first mentioned that the coal along Trail Creek was in a small synclinal remnant of the original deposit. Storrs (1902, p. 464) briefly referred to this district as a small synclinal basin in which the strata were overturned along the east edge. Calvert (1912a, p. 391) said that the coal occurred in a syncline bounded on the northeast side by two large (presumably normal) faults. Skeels (1939, p. 829) reinterpreted the faults described by Calvert to be one large thrust fault. Geologic mapping in the Maxey Ridge quadrangle (Roberts, 1964e) indicated that the fault dips 60°–90° NE. over most of its length; therefore, it is shown as a high-angle reverse fault (pl. 1). The coal beds in the northwest limb of the syncline adjacent to this fault are overturned.

On the north side of Trail Creek in the northern part of the district, the beds generally dip 45° NE.

They are upright west of the synclinal axis and ovreturned east of the axis. In the southern part near Trail Creek, dips vary considerably, and some beds are vertical. Several large normal faults were mapped near the Maxey Bros. mines; a diabase dike parallels and, doubtless, intrudes one of these faults in secs. 18–19, T. 3 S., R. 8 E. (pl. 1). Between Trail and Pine Creeks the district lies mostly in the irregular Pine Creek syncline, whose axis roughly parallels the Trail Creek syncline; the larger faults bound the lower valley of Trail Creek (pl. 1). The coal beds in the Livingston coal field that have the lowest recorded dips are those in the Pine Creek syncline.

Correlation of the coal beds in the Trail Creek district is very difficult because of the complex structure, erosion of the beds in the upper coal zone, and abrupt physical changes in all the beds. In the Mountain House mine at Hoffman, the upper coal zone—with the exception of the sequence between the Paddy Miles and Cokedale beds—is alternately layered coal and carbonaceous clastic rock (loc. 82, pl. 4). Designation of beds is by the interval at which they are mined, and correlation is based on their stratigraphic position and consistent clastic beds. The coal layers between the designated beds are generally discontinuous or lenticular.

The Big Dirty bed was prospected throughout the district but was not mined. The bed is 6–12 feet thick and consists of alternate bands of carbonaceous shale and impure coal.

The Maxey bed is the thickest and has fewer partings in the Trail Creek district, particularly near the Maxey Bros. mines (loc. 88, pl. 4). The Maxey coal bed at the Maxey Bros. mines is 9 feet thick and has two small partings 5–6 feet from the base. The bed thins progressively to the north and is only 1½ feet thick at the Monroe mine. The Maxey bed, which is 20–50 feet stratigraphically above the Big Dirty bed (pl. 2), was the source of most of the coal mined in the district.

The middle coal bed in this district is 40–90 feet stratigraphically above the Maxey bed. The bed is 3½ feet thick in the Gasaway tunnel; 7 feet thick at the Maxey Bros. mines (loc. 89, pl. 4); 5 feet thick 1 mile south of the Maxey Bros. mines (loc. 90, pl. 4); and 7 feet thick in Maxey Bros. drill hole MB–2 in sec. 3, T. 4 S., R. 8 E. The bed contains several partings (pl. 4); however, minable thicknesses of coal are present.

The Bottamy bed, 75 feet stratigraphically above the Middle bed, is thickest in the southern part of the Trail Creek district. It may correlate with the unnamed bed at the base of the upper coal zone near Chestnut. The Bottamy bed is 4–6 feet thick and contains several partings (locs. 91–95, pl. 4). Only the Bottamy Nos. 1 and 2 mines, near Pine Creek (pl. 1), produced coal from this bed.

The Storrs No. 3 bed is approximately 120 feet stratigraphically above the Bottamy bed in this district and consists of alternate bands of coal, bone, carbonaceous shale, and sandstone (pl. 1). Just north of the Sheep Corral workings of the Mountain House mine, this bed splits (loc. 79, pl. 4); in the southern workings of the Mountain House mine, the upper and lower splits of this bed are 30 feet apart. The bed ranges in thickness from 5 feet to more than 37 feet near Hoffman and from 7 to 8 feet near Chimney Rock; it contains many partings (locs. 82, 83, 87, pl. 4). The largest producer on the Storrs No. 3 bed in the Trail Creek district was the Mountain House mine. The Stevenson and Kountz mines also produced coal from this bed. Miners of the Sheep Corral workings of the Mountain House mine referred to this bed as the "Peacock" bed, owing to its iridescence.

The Paddy Miles bed is 4–25 feet above the Storrs No. 3 bed and is 3–4 feet thick (pl. 4). The bed was exposed in workings of the Mountain House and Kountz mines, but no coal was mined.

Very little is known about the Cokedale bed in this district. Miners cut a 4-foot bed in a crosscut near the bottom of the main slope of the Mountain House mine, at the approximate stratigraphic position (70 ft above the Paddy Miles bed) of the Cokedale bed (loc. 82, pl. 4). So far as is known, no coal was mined from this bed in the Trail Creek district.

BRIDGER CANYON DISTRICT

The Bridger Canyon district is a coal-bearing area east of Bridger Canyon and north of the Meadow Creek district (pl. 1). This district has been prospected intermittently for coal; however, no mines were developed. Two coal beds 20–25 feet apart, which cross the SE¼ sec. 34 and the NW¼ sec. 35, T. 1 S., R. 6 E., are interbedded in massive indurated sandstones. The beds dip 30°–85° NE. and are overturned. Correlatives of these beds in the other districts of the Livingston coal field have not been identified; however, the beds are in the lower coal zone and are perhaps equivalent to the Big Dirty and Maxey beds. The geology of this district was mapped in detail by Roberts (1964f).

The lower bed, which is 4 feet thick including many thin partings of bone and clay, is soft and exceedingly dirty throughout. This bed has no economic value both here and for several miles north and south. In the NE¼SE¼ sec. 34, a horizontal drift was driven 300 feet north on the strike of the lower bed. The quality of the coal remained poor, and the prospect was abandoned. Similarly, about 500 feet south of Bridger

Creek, another tunnel was driven south along the strike of this bed and later was abandoned.

The upper bed is 6 feet thick and, like the lower bed, is soft and dirty; it contains five distinct partings of bone or brown dirty coal. The bed may, therefore, be described as a series of partings 4–12 inches thick, between which are dirty bands of soft coal.

RANK AND QUALITY OF THE COAL

In the United States, coals are ranked in accordance with a standard classification adopted by the American Society for Testing Materials (1955) (table 1).

The coals of the Livingston coal field are high-volatile A, B, and C bituminous in rank (Combo and others, 1949, p. 14) and are generally of coking quality. Chemical analyses of the coal beds are listed in table 2. Most of these analyses predate the improved laboratory techniques of today; however, they are the only available analyses and differ but very slightly from those prepared according to improved techniques. All the coal beds in the Livingston coal field have one or more partings, and the mined coal must be washed to obtain a product with a sufficiently low ash content. Differences in chemical analyses of washed and unwashed coal samples from the Storrs No. 3 coal bed are listed in table 3.

The physical and chemical characters of the coal beds of the Livingston coal field vary greatly in different parts of the field primarily owing to conditions of formation. Tectonic deformation also affected the quality of the coal throughout the field. Local differences are so pronounced that, were it not for the evidence of the containing strata, correlation would be most difficult. The coal has been crushed in many areas by folding and faulting, and mines in these areas produced a large amount of fine-sized coal that was not of economic value at the time.

During the peak period of exploration in the Livingston coal field, Eldridge (1886, p. 748–750) examined the coal exposed in the many prospects and mines and observed the local variation from solid blocks to friable slickensided chips. This variation in the character of

TABLE 1.—*Classification of coals by rank*

[Standard Classification adopted by the American Society for Testing Materials (1955, p. 1022)]

Explanation: FC, fixed carbon; VM, volatile matter; Btu, British thermal units. This classification does not include a few coals which have unusual physical and chemical properties and come within the limits of fixed carbon or Btu of the high-volatile bituminous and subbituminous ranks. All these coals either contain less than 48 percent dry mineral-matter-free fixed carbon or have more than 15,500 moist mineral-matter-free Btu.

Class and group	Limits of fixed carbon or Btu mineral-matter-free basis	Requisite physical properties
I. Anthracitic:		
1. Meta-anthracite	Dry FC, 98 percent or more (dry VM, 2 percent or less)	
2. Anthracite	Dry FC, 92 percent or more and less than 98 percent (dry VM, 8 percent or less and more than 2 percent).	
3. Semianthracite	Dry FC, 86 percent or more and less than 92 percent (dry VM, 14 percent or less and more than 8 percent).	Nonagglomerating.[1]
II. Bituminous [2]:		
1. Low-volatile bituminous coal	Dry FC, 78 percent or more and less than 86 percent (dry VM, 22 percent or less and more than 14 percent).	
2. Medium-volatile bituminous coal	Dry FC, 69 percent or more and less than 78 percent (dry VM, 31 percent or less and more than 22 percent).	
3. High-volatile A bituminous coal	Dry FC, less than 69 percent (dry VM, more than 31 percent); and moist [3] Btu, 14,000 [4] or more.	
4. High-volatile B bituminous coal	Moist [3] Btu, 13,000 or more and less than 14,000 [4]	
5. High-volatile C bituminous coal	Moist Btu, 11,000 or more and less than 13,000 [4]	Either agglomerating or nonweathering.[5]
III. Subbituminous:		
1. Subbituminous A coal	do.[4]	Both weathering and nonagglomerating.
2. Subbituminous B coal	Moist Btu, 9,500 or more and less than 11,000 [4]	
3. Subbituminous C coal	Moist Btu, 8,300 or more and less than 9,500 [4]	
IV. Lignitic:		
1. Lignite	Moist Btu, less than 8,300	Consolidated.
2. Brown coal	do	Unconsolidated.

[1] If agglomerating, classify in low-volatile group of the bituminous class.

[2] Noncoking varieties may occur in each group of the bituminous class.

[3] Moist Btu refers to coal containing its natural bed moisture but not including visible water on the surface of the coal.

[4] Coals having 69 percent or more fixed carbon on the dry mineral-matter-free basis shall be classified according to fixed carbon, regardless of Btu.

[5] There are three varieties of coal in the high-volatile C bituminous coal group—namely, variety 1, agglomerating and nonweathering; variety 2, agglomerating and weathering; variety 3, nonagglomerating and nonweathering.

the coal resulted, in part, from varying lateral readjustments in the coal beds during the folding. The folding and shearing that took place in the coal beds in this area are excellently indicated by the numerous contorted partings at an exposure of the Big Dirty bed, NW¼NW¼ sec. 26, T. 2 S., R. 8 E. (fig. 3). The chippy coal was easily mined by pick, whereas most of the blocky coal required undercutting and blasting.

The upper coal zone beds generally consist of bright-banded coal having a prismatic cleat. Beds in the lower coal zone generally include bright- and dull-banded coal having a blocky to platy cleavage. Most coal beds in both zones contain impurities and widespread shale or clay partings.

Coking properties of coal vary between beds and within a bed. The localities that yielded good coke are along the flanks of the anticlines. Coal from synclines and the plunging end of the anticlines yielded poor coke or would not coke. The synclines are much tighter than the anticlines, and the plunging end of the anticlines is much more faulted than are the flanks (pl. 1). Thus, coal having the best coking properties is found in areas of the least tectonic influence in the Livingston coal field. This fact indicates that coking properties are probably gradually destroyed by the amount of cleavage, thereby permitting a greater surface of coal per volume to unite with oxygen.

All the coal mined at Cokedale from the Cokedale and Middle beds yielded coke; however, owing to the folding and shearing of the beds, many small partings became admixed with the coal, and washing was required to reduce the ash content. Samples of the Cokedale coke were well fused, fine grained, and of bright metallic luster. Smith [1] made the following proximate analysis of coke from a sample of the Middle bed taken from a pillar in the Cokedale No. 3 mine: Fixed carbon, 81.54 percent; volatiles, 1.96 percent; and ash, 16.50 percent.

During 1902–07 the Washoe Coal Co. invested nearly $1 million in developing mines and constructing facilities for producing coke at Storrs, Mont. The mines were along the strike of the coal beds in a tightly folded syncline. The coal was generally crushed or broken and admixed with some of the clastic partings; much of the clastic material could not be separated from the coal either during the mining or by washing. In 1908, just after the Washoe Coal Co's. operations closed, coking tests (table 4) and chemical analyses of the coke from the Storrs No. 3 coal bed (table 5) were made. These tests showed a high ash content, which could not be reduced within the 20-percent allowed limit for coke.

[1] Smith, G. R., 1954, Carbonization of Montana coal: Bozeman, Montana State College unpub. M.S. thesis, p. 36.

More than 20 localities in the Livingston coal field were examined radiometrically by Hail and Gill (1953, p. 2). No abnormal radioactivity was detected in the coals in the field, nor did any sample contain more than 0.002 percent uranium in the ash.

Comparison with coal from other coal fields in Montana.—The coal-bearing formations in Montana are of Jurassic, Cretaceous, and Tertiary age. The Fort Union Formation of Paleocene age contains more than 90 percent of the total State reserves (Combo and others, 1949, p. 3). Other coal-bearing units are the Morrison Formation of Late Jurassic age, the Eagle Sandstone and Judith River Formations of Late Cretaceous age, the Tullock Member of the Fort Union Formation of Paleocene age, and the Wasatch Formation of Eocene age. The average proximate analysis of coal from major beds in selected coal fields of Montana and a generalized stratigraphic section of coal-bearing formations (fig. 7) show that coal from the Livingston coal field is among the best in the State.

COAL PRODUCTION

Coal for local domestic use was produced in the Livingston coal field during the 1870's. The coal-mining industry of this field began in the early 1880's (U.S. Dept. Interior, 1886, p. 899) with the production of 224 short tons of coal from the Rocky Canyon mine. Coal mining in the Livingston field increased from 1880 to 1910 owing to the increased use of coal for railroad operations, domestic fuel, and smelting. Maximum annual production of 601,598 tons was recorded in 1895 (U.S. Geol. Survey, 1897, p. 552). In the early 1900's an improved method for smelting copper that required much less coke initiated the decline of coal production in this field. Also, coal production for railroad operations began to decline (ending in 1910) in the Livingston field, while production for railroad operations from mines at Red Lodge, Mont., increased. Production sharply declined from 1910 to 1916, the last year of record before World War I. After World War I, annual production was only a few thousand tons, or less, for domestic trade; and in some years no production was recorded. Open-pit coal mining in eastern Montana, which supplied most of the Montana coal market after 1924, discouraged redevelopment in the Livingston field. In response to local needs for lower cost domestic fuel during the depression of the 1930's, coal production in the Livingston field revived slightly, but by 1942 it had ceased. The total recorded coal production, in short tons, and its value in Gallatin and Park Counties are given in table 6; production of individual mines, if known, is given under the description of the mine.

TABLE 2.—*Chemical analyses of coals from the Livingston coal field, Montana*

[U.S. Bur. Mines analyses made before 1913 and bearing sample numbers below 16100 were made by methods for determining volatile matter and fixed carbon which were not standard with respect to temperature; consequently, determinations made before this date are not closely comparable with those made after 1913, when a standard temperature was adapted. Sources of data: Eldridge (1886, p. 780 and 782); Belden, Dalamater, and Groves (1909, p. 15); Calvert (1912a, p. 46); Lord and others (1913, p. 133); USBM (U.S. Bur. Mines, 1932, p. 48–49, 54–55). Kind of sample: M, mine; S, surface; T, tipple. Form of analysis: A, as received; B, dried until weight is constant; C, moisture free; D, moisture and ash free]

Location (sec.)	Mine or prospect	Coal bed	Source of data	Measured coal section No. on plate 1	Thickness of coal analyzed (in.)	Laboratory No.	Kind of sample	Form of analysis	Analyses, in percent: Proximate: Moisture	Volatile matter	Fixed carbon	Ash	Ultimate: Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Air-drying loss (percent)	Heating value (Btu)	Remarks
									T. 2 S., R. 6 E.											
13	Bailey and Beadle mine.	Cokedale	Calvert		38	6621	T	A	2.1	16.4	73.2	8.31	4.08	81.03	1.28	4.44	0.86		14,090	
								B	.6	16.7	74.3	8.44	3.97	82.26	1.30	3.16	.87	1.5	14,310	
								C		16.7	74.8	8.48	3.93	82.72	1.31	2.68	.88		14,390	
								D		18.3	81.7		4.29	90.39	1.43	2.93	.96		15,720	
									T. 2 S., R. 7 E.											
20	Thompson No. 2 prospect.	Cokedale	Eldridge	1	75	7	S	A	10.64	34.64	42.86	11.86					0.32	3.94		Excluding partings, aggregating.
					117	8	S	A	9.74	31.43	38.25	20.53					.40	3.16		Including bone and clay partings, aggregating.
	Chestnut mine rock tunnel.	Storrs No. 3	do	7	85	1	M	A	1.03	39.48	41.37	18.12					.64	1.02		5 benches, aggregating. Coke; good. Sample from intersection of tunnel and coal bed.
21	Rocky Canyon coal mine.	Cokedale	do		36	10	M	A	3.78	23.08	59.27	13.87					.66	.77		Sample location unknown.
					18	11	M	A	3.91	33.48	52.04	10.57					.46	.83		Coal cokes. Sample location unknown.
					12	2	M	A	.75	20.00	61.74	8.51					.66	.75		Upper middle bench. Sample location unknown.
					14	3	M	A	.80	14.68	71.56	12.96					.58	.19		Lower middle bench. Sample location unknown.
	Mountain Side mine.	do	Calvert			3667	M	A	5.4	27.0	37.0	30.63	4.24	50.58	0.81	13.41	.33		9,030	Sample location unknown.
								B	2.7	27.7	38.1	31.51	4.04	52.04	.83	11.24	.34		9,300	
								C		28.5	39.1	32.37	3.85	53.46	.86	9.11	.35	2.8	9,550	
								D		42.1	57.9		5.69	79.04	1.27	13.48	.52		14,120	
	Unnamed prospect.	do	Eldridge	9	33	5	S	A	16.48	34.30	40.22	9.00					.36	3.61		Excluding partings.
				9	75	6	S	A	14.01	30.11	32.35	23.53					.27	4.94		Including clay partings.
	Unnamed prospect.	Unnamed bed at base of upper coal zone.	do	10	23	4	M	A	1.58	42.11	48.66	7.65					.61	.82		3 benches of coal (total thickness 3 ft 7 in.) aggregating. Coke; good. Sample location unknown.
24	Timberline No. 1 mine.	Cokedale	do	15		(6)	M	A	3.02	36.14	43.45	17.39					.45	1.04		Sample from dump.
							M		5.48	5.84	77.89	10.79					.43	1.35		Analysis of the coke.
					43		M	A	1.83	38.35	50.20	9.62					.52	1.10		4 benches aggregating. Coke; good. Sampled at portal.
				16	18	9	M	A	9.37	35.70	49.77	5.16					.45	3.17		Upper bench. Sample from face 60 ft from portal.
					37	10	M	A	3.62	35.01	44.50	16.87					.43	1.06		Lower bench, excluding 2-in. parting. Sample from face 60 ft from portal.
				17	11	1	M	A	1.97	41.55	51.13	5.35					.54	.68		Top bench. Coke; good. Sample from face 195 ft from portal.
					8	2	M	A	1.76	29.38	26.28	42.58					.47	.52		Upper middle bench. Coke; poor. Sample from face 195 ft from portal.
					10	3	M	A	1.12	31.77	49.72	17.39					.45	.47		Middle bench. Coke; good. Sample from face 195 ft from portal.
					8	4	M	A	1.60	38.57	50.91	8.92					.57	1.08		Lower middle bench. Coke; good. Sample from face 195 ft from portal.
					4½	5	M	A	1.28	38.71	45.89	14.12					.59	1.13		Upper bottom bench. Coke; good. Sample from face 195 ft from portal.
					10	6	M	A	1.66	37.71	46.46	14.17					.52	1.43		Bottom bench. Coke; good, rather dense. Sample from face 195 ft from portal.

					11	7	M	A	1.13	41.18	53.91	3.78					.59	.97		Top bench. Coke; good but dense. Sample from face 220 ft from portal.
					7	8	M	A	1.69	25.30	21.81	51.20					.64	1.26		Upper middle bench. Sandy coke. Sample from face 220 ft from portal.
				18	20½	9	M	A	1.27	36.94	52.62	9.17					.58	1.08		Lower middle bench. Coke; fair. Sample from face 220 ft from portal.
					18	10	M	A	1.29	35.52	43.44	19.75					.52	1.11		Bottom bench. Coke; fair. Sample from face 220 ft from portal.
				19	48½	14	M	A	1.57	35.66	48.88	13.89					.58	.59		4 benches, aggregating. Coke; fair. Sample from face 231 ft from portal.
	Hyer's prospect	do	Eldridge	44	45½	13	M	A	8.20	34.18	45.15	12.47					.50	2.95		5 benches, aggregating. Sample from face 33 ft from portal.
				45	79	(a)	M	A	2.74	39.63	48.88	8.75					.65	1.18		9 benches, aggregating. Coke; good. Sampled at portal.
							M		4.48	9.82	76.25	9.45					.71	1.21		Analysis of the coke.
							M	A	1.99	37.76	47.43	12.82					.77	.88		Coke good. Sample location unknown.
					18	11	M	A	9.37	33.78	47.19	9.66					.42	2.75		Upper bench, excluding waste streaks. Sample from face 60 ft from portal.
				46	20	12	M	A	8.89	35.23	38.76	17.12					.46	2.65		Middle bench, excluding waste streaks. Sample from face 60 ft from portal.
					38	13	M	A	5.59	34.46	49.41	10.54					.49	1.71		Lower bench, excluding waste streaks. Sample from face 60 ft from portal.
					13	1	M	A	1.55	36.61	47.31	14.53					1.38	.89		Hanging-wall seam, top bench. Coke; good, but dense. Sample from face 200 ft from portal.
					12	3	M	A	1.56	37.25	49.41	11.78					.56	.72		Hanging-wall seam, lower top bench. Coke; good. Sample from face 200 ft from portal.
25	Timberline No. 6 mine.	do	do		4	4	M	A	1.35	30.45	43.22	24.98					.45	.73		Hanging-wall seam, upper middle bench. Coke; rather poor. Sample from face 200 ft from portal.
					5	5	M	A	1.46	39.15	47.26	12.13					.57	.73		Hanging-wall seam, middle bench. Coke; good, but dense. Sample from face 200 ft from portal.
					4	6	M	A	1.09	39.11	43.79	16.01					.55	.74		Hanging-wall seam, lower middle bench. Coke; good. Sample from face 200 ft from portal.
				47	4	7	M	A	1.98	36.47	48.94	12.61					.91	.96		Hanging-wall seam, bottom bench. Coke; good. Sample from face 200 ft from portal.
					4	8	M	A	1.54	39.89	49.92	8.65					.67	.64		Footwall seam, top bench. Coke; good. Sample from face 200 ft from portal.
					7½	9	M	A	1.68	39.98	48.78	9.56					.84	.87		Footwall seam, upper middle bench. Coke; good. Sample from face 200 ft from portal.
					8	10	M	A	1.87	36.60	47.96	14.17					.62	.93		Footwall seam, lower middle bench. Coke; good, but dense. Sample from face 200 ft from portal.
					14	11	M	A	1.92	38.45	50.11	9.52					.64	1.92		Footwall seam, bottom bench. Sample from face 200 ft from portal.
								A	4.85	29.98	36.45	28.72					.51			
								B	1.91	30.91	37.57	29.61					.53	3.0		
			Belden and others; Calvert.	40	60	166-D	M	C		31.51	38.30	30.19					.54			Sample from face 4,600 ft from portal.
	Washoe Coal Co. No. 3 mine.	Cokedale						D		45.2	54.8						.80			
								A	4.01	34.54	45.48	15.97					.51		11,860	
			Beldon and others; USBM.	41	73	167-D	M	B	2.05	35.24	46.41	16.30					.52	2.0		Sample from face 4,000 ft from portal.
26								C		35.98	47.38	16.64					.53		12,355	
								D		43.16	56.84						.64		14,821	
								A	5.8	33.1	50.5	10.57	5.38	69.23	1.01	13.31	.50		12,280	
	Hodson mine	do	Calvert	42	37	6597	M	B	2.0	34.5	52.5	10.99	5.16	71.96	1.05	10.32	.52	3.8	12,770	Sample from pillar between rooms 1 and 2.
								C		35.2	53.6	11.22	5.08	73.47	1.07	8.68	.53		13,030	
								D		39.6	60.4		5.67	82.75	1.21	9.77	.60		14,680	
								A	6.25	32.41	45.65	15.69	5.20	63.35	.91	14.41	.44	4.5	11,455	
35	Washoe Coal Co. No. 1 mine.	Paddy Miles	USBM			3691	M	C		34.57	48.69	16.74	4.81	67.58	.97	9.43	.47		12,218	Sample location unknown.
								D		41.52	58.48		5.78	81.16	1.16	11.34	.56		14,675	

See footnotes at end of table.

TABLE 2.—*Chemical analyses of coals from the Livingston coal field, Montana*—Continued

Location (sec.)	Mine or prospect	Coal bed	Source of data	Measured coal section No. on plate 1	Thickness of coal analyzed (in.)	Laboratory No.	Kind of sample	Form of analysis	Analyses, in percent: Proximate: Moisture	Volatile matter	Fixed carbon	Ash	Ultimate: Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Air-drying loss (percent)	Heating value (Btu)	Remarks
									T. 2 S., R. 8 E.											
21	Unnamed prospect	Cokedale	(1)	24		(6)	M	A	2.4	38.0	50.0	9.6								Sample location unknown.
	Hubbard mine	Middle	(1)			(6)	M	A	2.5	40.0	42.0	9.5								Do.
					50	(6)	S	A	21.21	34.43	30.80	13.56					0.34	7.28		
	Cokedale No. 2 mines	Cokedale	Eldridge	26	4	1	M	A	11.76	35.69	36.32	16.23					.47	6.27		Upper bench.
					19½	2	S	A	9.24	35.85	49.34	5.57					.37	4.85		Upper middle bench.
					6	3	S	A	10.85	37.17	44.50	7.48					.39	5.82		Middle bench.
					6	4	S	A	8.34	37.94	38.74	14.98					.36	4.75		Lower middle bench.
					14	6	S	A	11.33	35.24	47.67	5.76					.45	4.27		Lower bench.
22	Cokedale No. 2 mines—Sugar Loaf entry.	Paddy Miles	do	27	80½	15	M	A	3.50	34.86	53.17	8.67					.52	1.52		4 benches, aggregating. Sample from face 38 ft from portal.
	Cokedale No. 3 mine.	Middle	do	29		(6)	S	A	12.51	37.63	32.83	17.03					.47	4.34		
	Unnamed prospect	Cokedale(?)	Calvert		31	6596	S	A	6.2	30.6	36.9	26.26	4.77	53.79	0.86	34.64	.68		9,790	Sample from working face. Prospect 500 ft west of Northern Pacific Coal Co. mine.
								B	1.7	32.1	38.7	27.53	4.47	56.38	.90	10.01	.71	4.6	10,260	
								C		32.6	39.4	28.01	4.34	57.38	.92	8.62	.73		10,450	
								D		45.3	54.7		6.03	79.71	1.28	11.97	1.01		14,510	
				56		(6)	M	A	2.56	38.81	43.04	15.59					1.94	1.10		Coke; good. Sample from face 53 ft from portal.
				57			M	A	2.73	34.34	38.85	24.08					.86	.64		Coke; good. Sample from face 60 ft from portal.
					8	1	M	A	1.40	34.78	51.54	12.28					.52	.96		Upper bench. Coke; good. Sample from face 80 ft from portal.
				59	12	2	M	A	1.36	38.47	44.51	15.66					.54	1.06		Middle bench. Coke; good. Sample from face 80 ft from portal.
					43	3	M	A	1.52	35.93	39.81	22.74					.69	.71		Lower bench. Coke; good. Sample from face 80 ft from portal.
					7	1	M	A	.97	30.90	42.80	25.33					.47	.76		Top bench. Coke; poor. Sample from face 148 ft from portal.
24	Northern Pacific Coal Co. mine.	Cokedale	Eldridge	60	11	2	M	A	1.10	32.81	40.87	25.22					.50	.59		Upper middle bench. Coke; good. Sample from face 148 ft from portal.
					27	3	M	A	1.46	34.65	37.57	26.92					.59	.52		Lower middle bench. Coke; good. Sample from face 148 ft from portal.
					6	4	M	A	1.23	40.74	42.53	15.50					.79	.67		Lower bench. Coke; good. Sample from face 148 ft from portal.
					42	5	M	A	.93	39.05	45.94	14.08					.68	.85		Middle bench. Coke; good. Sample from face 200 ft from portal.
				61	48	6	M	A	1.13	41.18	53.91	3.78					.59	.97		Lower bench. Coke; good. Sample from face 200 ft from portal.
					54	16	M	A	1.31	34.66	42.01	22.02					.57	.66		Middle bench. Coal; good. Sample from face 280 ft from portal.
26	Cokedale No. 1 mines.	do	do	55		(6)	M	A	2.03	35.07	35.62	27.28					.57	.77		Coke; good. Sampled at portal.
	Unnamed prospect	do	do	63		(6)	M	A	2.47	27.88	25.89	43.76					1.24	1.20		Coke; poor.
							M		5.70	6.00	78.09	10.21					.67	1.88		Analysis of the coke.
						(6)	M	A	6.69	32.39	39.50	21.43					.49	1.96		
					5½	1	M	A	9.98	35.93	44.35	9.74					.50	6.26		Top bench.
				72	12	2	M	A	4.55	33.12	52.45	9.88					.53	2.72		Upper middle bench.
					12	3	M	A	2.90	35.45	54.94	6.71					.57	1.39		Lower middle bench. Coke; poor, dense.
32	Small mine, unnamed.	do	do		8	4	M	A	2.89	36.20	50.08	10.83					.60	1.37		Bottom bench. Coke; poor, dense.
				73	16	12	M	A	4.81	33.90	36.49	24.80					.50	2.61		Top bench. Sample from face 71 ft from portal.
					33½	11	M	A	2.49	35.37	48.74	13.40					.66	1.93		3 benches, aggregating. Sample from face 71 ft from portal.

T. 2 S., R. 9 E.																				
28	Kangley mine	Cokedale	(2 3)	66		(6)	M	A	1.92	37.12	50.85	10.11								
T. 3 S., R. 8 E.																				
	Unnamed prospect.	Storrs No. 3	(2 3)	79		(6)	M	A	9.02	36.99	47.76	6.23								Sample from a prospect drift.
	Sheep Corral mine.	do	(2 3)	80		(6)	M	A	8.60	34.39	52.34	4.67								Sample from a branch gangway, location unknown. Mine operated as a part of the Mountain House mine.
18	Mountain House mine.	do	Calvert	81	98	3813	M	A	12.5	31.0	39.6	16.9					0.50			Sample from third entry 800 ft west of foot of slope.
								B	9.4	32.1	41.0	17.5					.52	3.4		
								C		35.5	45.2	19.3					.57			
								D		44.0	56.0						.70			
					62	3818	M	A	12.4	36.8	42.3	8.51	5.64	62.53	0.93	21.78	.67		10,950	Sample from head of west entry, 1,200 ft north of slope.
								B	9.8	37.9	43.5	8.77	5.48	64.40	.95	19.77	.63	2.9	11,280	
								C		42.1	48.2	9.72	4.86	71.38	1.06	12.28	.70		12,500	
								D		46.6	53.4		5.39	79.06	1.18	13.60	.77		13,840	
		Paddy Miles	USBM	82		3821	M	A	13.18	33.44	36.91	16.47	5.34	52.63	.86	24.07	.63	3.0	9,518	Sample location unknown.
								C		38.52	42.51	18.97	4.47	60.62	.99	14.22	.73		10,964	
								D		47.53	52.47		5.52	74.81	1.22	17.55	.90		13,531	
		Storrs No. 3	USBM	83		3814	M	A	10.42	28.64	30.00	30.94					.44	2.1		Sample from face 325 ft from No. 3 entry.
								C		31.97	33.49	34.54					.49			
								D		48.84	51.16						.75			
			(2 4)	86		(6)	M	A	9.31	34.75	47.34	8.60								Sample from southeast slope gangway.
							M	A	8.87	33.08	49.48	8.57								Do.
20	Kountz mine	Paddy Miles(?)	Calvert	87		3725	M	A	11.7	36.4	41.4	10.52	5.40	61.17	.87	21.65	.39		10,760	Sample location unknown.
								B	8.4	37.8	42.9	10.92	5.18	63.52	.90	19.07	.41	3.7	11,170	
								C		41.2	46.9	11.92	4.63	69.31	.99	12.71	.44		12,190	
								D		46.8	53.2		5.26	78.70	1.12	14.42	.50		13,840	
	Maxey Bros. No. 2 mine.	Maxey	do	88	108	6607	M	A	16.3	30.1	40.1	13.50	5.15	53.48	.82	26.04	.41		9,250	Sample from face 825 ft from portal.
								B	7.6	33.3	44.2	14.90	4.54	59.03	.90	20.18	.45		10,210	
								C		36.0	47.9	16.13	3.99	63.92	.98	14.49	.49	9.4	11,050	
								D		42.9	57.1		4.70	76.21	1.17	17.28	.58		13,180	
			(2 3)			3	M	A	16.67	32.12	44.78	6.43								Sample location unknown.
						4	M	A	13.21	36.89	43.71	6.19							10,619	Do.
						5	M	A	8.60	32.00	51.70	7.70								Do.
						6	M	A	9.20	31.80	49.90	9.19							10,225	Do.
28	Maxey Bros. Prospect.	Middle	(5)	89		B-22766	M	A	20.4	30.3	38.5	10.8	5.9	51.9	.9	30.1	.4		8,920	Sample from face 135 ft from portal.
								B	14.1	32.7	41.5	11.7	5.5	56.0	1.0	25.4	.4	7.3	9,630	
								C		38.1	48.3	13.6	4.6	65.2	1.1	15.0	.5		11,210	
								D		44.1	55.9		5.3	75.5	1.3	17.3	.6		12,980	
						B-22767	M	A	18.1	29.5	38.3	14.1	5.6	51.3	.8	27.8	.4		8,810	Sample from face 110 ft from portal.
								B	12.7	31.4	40.9	15.0	5.2	54.7	.9	23.8	.4	6.2	9,390	
								C		36.0	46.8	17.2	4.3	62.6	1.0	14.4	.5		10,760	
								D		43.5	56.5		5.2	75.7	1.2	17.3	.6		12,990	
						B-22768	M	A	19.2	30.0	38.2	12.6	5.8	51.7	.9	28.6	.4		8,860	Composite of samples B-22766 and B-22767.
								B	13.3	32.2	41.0	13.5	5.4	55.4	.9	24.4	.4	6.8	9,500	
								C		37.1	47.4	15.5	4.5	64.0	1.1	14.4	.5		10,960	
								D		43.9	56.1		5.3	75.7	1.3	17.1	.6		12,980	

1 Analysis courtesy of Am. Smelting & Refining Co.; date of analysis, 1925.
2 Analysis courtesy of Northern Pacific Ry. Co.
3 Date of analysis: 1912.
4 Date of analysis: 1907.
5 U.S. Bur. Mines; date of analysis, 1937.
6 No number assigned by laboratory.

TABLE 3.—*Chemical analyses of coal from the Storrs No. 3 coal bed, NW¼ sec. 35, T. 2 S., R. 7 E., Meadow Creek district of the Livingston coal field, Montana*

[From Belden, Delamater, and Groves (1909, p. 28). All data reduced to a dry basis for better comparison]

Test No.	Raw coal				Washed coal								Refuse			
	Volatile matter	Fixed carbon	Ash	Sulfur	Volatile matter	Fixed carbon	Ash			Sulfur			Volatile matter	Fixed carbon	Ash	Sulfur
							Percent	Reduction (percent)	Removed (percent)	Percent	Reduction (percent)	Removed (percent)				
207	30. 90	36. 91	32. 19	0. 54	35. 53	44. 31	20. 16	37	61	0. 61	------	30	23. 34	26. 43	50. 23	0. 58
211	30. 90	36. 91	32. 19	. 54	35. 18	44. 47	20. 35	37	60	. 64	------	24	22. 53	23. 11	54. 36	. 65
212	30. 90	36. 91	32. 19	. 54	34. 84	44. 97	20. 19	37	66	. 58	------	41	22. 70	21. 71	55. 59	. 61
212[1]	30. 90	36. 91	32. 19	. 54	36. 83	47. 82	15. 35	52	77	. 60	------	46	27. 63	42. 18	30. 19	. 58

[1] Rewashed coal from test 212.

TABLE 4.—*Coking tests of coal from the Storrs No. 3 coal bed, NW¼ sec. 35, T. 2 S., R. 7 E., Meadow Creek district of the Livingston coal field, Montana*

[From Belden, Delamater, and Groves (1909, p. 40). r. o.m., run of mine; w., washed; f.c., finely crushed; n.c., not crushed]

	Test 207	Test 208	Test 212	Test 213
Date	Jan. 10, 1908	Jan. 12, 1908	Jan. 27, 1908	Jan. 29, 1908
Duration, hours	55	34	37	50
Size:				
As shipped	r.o.m.	r.o.m.	r.o.m.	r.o.m.
As used	w., f.c.	w., f.c.	w., f.c.	w., n.c.
Coal charged:				
Wet, pounds	10, 560	8, 660	8, 230	4, 950
Dry, do	9, 611	7, 903	7, 591	4, 474
Coke produced:				
Wet, pounds	5, 780	3, 900	4, 437	2, 100
Wet, percent	54. 73	45. 04	53. 91	42. 42
Dry, pounds	5, 750	3, 893	4, 417	2, 042
Dry, percent	59. 83	49. 26	58. 19	45. 64
Breeze produced:				
Wet, pounds	1, 412	1, 170	720	944
Wet, percent	13. 37	13. 51	8. 75	19. 07
Dry, pounds	1, 405	1, 168	717	918
Dry, percent	14. 62	14. 78	9. 44	20. 52
Total yield:				
Wet, do	68. 10	58. 55	62. 66	61. 49
Dry, do	74. 45	64. 04	67. 63	66. 16
Physical properties of coke:				
Specific gravity:				
Apparent	. 92	. 92	. 85	1. 03
Real	1. 88	1. 87	1. 87	1. 89
Volume:				
Coke, percent	49. 00	49. 00	45. 00	54. 00
Cells, do	51. 00	51. 00	55. 00	46. 00
Weight per cubic foot:				
Wet, pounds	88. 89	89. 08	87. 06	91. 14
Dry, do	57. 07	57. 26	52. 77	62. 45
6-ft drop test over 2-in. mesh:				
1, percent	85. 00	86. 00	95. 50	80. 50
2, do	73. 00	74. 00	90. 00	61. 00
3, do	62. 00	61. 50	83. 00	48. 50
4, do	54. 50	53. 50	76. 00	35. 50
5, do	74. 00	65. 50	80. 50	47. 50

REMARKS

Test 207: Dull-gray color. No apparent cell structure. Not coked down to bottom. Large amount of breeze and high volatile in coke probably due to this. Soft, punky, dense coke. Impossible to wash coal enough to reduce ash of coke within allowed limits.

Test 208: Same as 207.

Test 212: Rewashing of washed coal reduced ash content of coke to 22.07 percent and reduced percentage of breeze, but did not materially better coke.

Test 213: Attempt to improve rewashed charge of 212 by not crushing. Breeze very much increased and cross fracture of coke more highly pronounced.

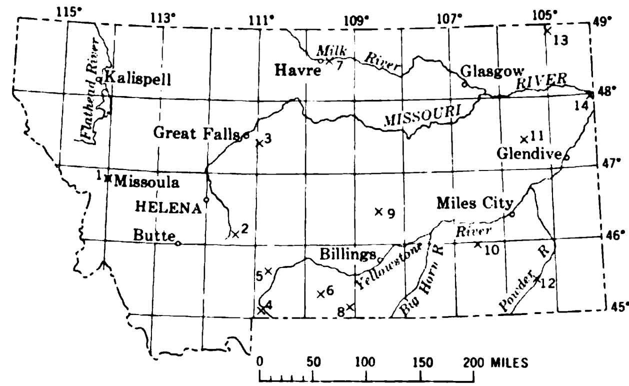
Most production from the Timberline and Meadow Creek districts was consumed in the operations of the Northern Pacific Railway. Production from mines in the Cokedale district went primarily into the manufacture of coke which was used in the copper smelters of western Montana. Mines of the Trail Creek district produced for the domestic heating market, mostly in Bozeman, Livingston, and Helena.

COKE PRODUCTION

The Cokedale district of the Livingston coal field began coke production in the 1880's during the early development of the silver and copper mines in western Montana and furnished coke to these mines and to smelters at Anaconda, Butte, and East Helena. Maximum coke production was attained in the 1890's; thereafter, production declined gradually, and by 1896 it had stopped at Cokedale. The Electric coal field near Gardiner was then the principal producer in Park County. The small production reported from Gallatin County consisted of tests at Chestnut and Storrs, and neither of these localities became commercial producers of coke. A small amount of coke was produced at Cokedale in the early 1900's, but the mines there were abandoned in 1906. Coke production stopped in the Electric coal field in 1911 (U.S. Bur. Mines, 1932, p. 20). Recorded production of coke in Gallatin and Park Counties during 1889–1910 is given in table 7. Before 1889, coke production was not recorded, and little is known regarding production in the Livingston coal field before that time. A total of 19,450 short tons of coke was manufactured in Montana during 1883–88 (U.S. Geol. Survey, 1901, p. 585), of which approximately half was produced at Cokedale. The yield of coke from coal was approximately 50 percent (U.S. Geol. Survey, 1901, p. 585).

Coke was manufactured at Cokedale and Storrs in beehive ovens. Cokedale had 115 ovens, and Storrs had 100 finished ovens and 100 unfinished ovens (Rowe, 1906, p. 77). The average charge of coal to each oven was 3.4 tons. The coke yield was 1 ton from 1.6 tons of coal.

Era and Period		Series	Formation and Member		Missoula (1)	Lombard (2)	Belt (3)	Electric (4)	Livingston (5)	Stillwater (6)	Milk River (7)	Red Lodge (8)	Roundup (9)	Colstrip (10)	McCone Co (11)	Broadus (12)	Sheridan Co (13)	Girard (14)
					Field or area													
Cenozoic	Tertiary	Miocene or Oligocene	Kishenehn(?) Formation of Daly (1913)		X													
		Eocene	Wasatch Formation															
		Paleocene	Fort Union Formation	Tongue River Member								X	X	X	X	X		X
				Lebo Shale Member														
				Tullock Member														
Mesozoic	Cretaceous	Upper	Hell Creek Formation (Lance Fm)														X	
			Lennep Sandstone (Fox Hills Sandstone)															
			Bearpaw Shale															
			Judith River Formation								X							
			Claggett Shale															
			Eagle Sandstone					X	X	X								
			Telegraph Creek Formation															
			Colorado Shale															
		Lower	Kootenai Formation															
	Jurassic	Upper	Morrison Formation			X	X											



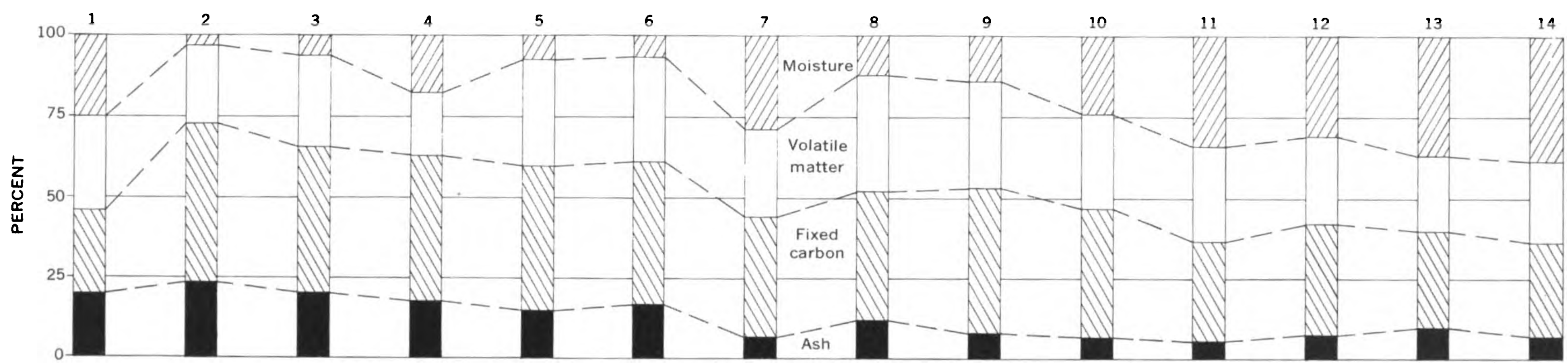


FIGURE 7.—Average proximate analysis of coal from major coal beds in selected coal fields of Montana, "as received" basis.

TABLE 5.—*Chemical analyses of coke from the Storrs No. 3 coal bed, NW¼ sec. 35, T. 2 S., R. 7 E., Meadow Creek district of the Livingston coal field, Montana*

[From Belden, Delamater, and Groves (1909, p. 41)]

Test No.	Laboratory No.			Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Phos-phorus
207	229-D	Coal	Wet	8.99	32.33	40.34	18.34	0.55	
			Dry		35.53	44.31	20.16	.61	
	235-D	Coke	Wet	.52	1.42	71.94	26.12	.56	0.0177
			Dry		1.43	72.31	26.26	.56	
208	234-D	Coal	Wet	8.74	32.11	40.58	18.57	.59	
			Dry		35.18	44.47	20.35	.64	
	236-D	Coke	Wet	.18	1.26	70.60	27.96	.51	.0175
			Dry		1.26	70.73	28.01	.51	
212	253-D	Coal	Wet	7.76	33.97	44.11	14.16	.55	
			Dry		36.83	47.82	15.35	.60	
	265-D	Coke	Wet	.46	2.00	75.47	22.07	.55	.0100
			Dry		2.01	75.82	22.17	.55	
213	263-D	Coal	Wet	9.61	33.00	42.34	15.05	.46	
			Dry		36.50	46.85	16.65	.51	
	266-D	Coke	Wet	2.78	2.03	74.13	21.06	.58	.0125
			Dry		2.09	76.25	21.66	.60	

HISTORY OF MINING

Coal was mined on a small scale for local use at many localities in Montana during the 1860's and 1870's; however, it was not mined industrially until the early 1880's. In 1865 a coal mine was opened in the Big Hole Valley, about 60 miles northeast of Bannack, and another opened near Argenta (McDonald and Burlingame, 1956, p. 24). About the same time, a mine was opened near Virginia City; and in 1866 a mine was opened on Mullen Pass, about 15 miles west of Helena. Coal was discovered in the Livingston coal field in 1867. The coal deposits at Belt were prospected in 1876. About this same time a mine was opened 6 miles north of Miles City, and the Bull Mountain coal field was prospected. The Red Lodge coal field was opened in 1882, and the upper Yellowstone Valley coal deposits near Gardiner were opened in 1883.

The Federal Government and the Northern Pacific Railway Co. made many reconnaissance surveys across the Pacific Northwest before the final transcontinental route was established. Areal distribution and quality of coal deposits in Montana influenced the location of the Northern Pacific Railway route across Montana. The Livingston coal field was investigated, and considerable coal-bearing land was acquired or leased by the Northern Pacific Railway Co. or by one of its subsidiaries. Within a year after completion of the transcontinental route, the mines at Timberline and Chestnut were supplying fuel for locomotives and shops throughout the Pacific Northwest, as well as to local domestic consumers.

The coal industry in the Livingston coal field grew steadily until the end of the 19th century. Then it declined very rapidly because (1) the best and most readily mined coal had been exploited, and better mining methods and machinery were required to mine the remaining coal; (2) an improved method for smelting copper was developed that required less coke; (3) technological advances made the price of lower rank coals in the eastern part of the State more competitive, for these coals could be strip mined at much less cost; and (4) coal was replaced by oil as a fuel.

Use of coal as a domestic fuel renewed mining activity in the Livingston coal field on a very small scale in the early 1930's. Several prospects were developed into small mines, and older mines were reopened; but little is known of these mines because only a few, scattered records were kept. As the general economy of the area improved during the 1930's, commercial production ceased.

In the early 1880's the Northern Pacific Railway Co. established the Northern Pacific Coal Co. to develop its mines in the Pacific Northwest. This subsidiary company developed a small mine at Cokedale; however, its first large operation in the Livingston coal field was the Timberline mines. About 1895 the Northern Pacific Railway Co. acquired the Rocky Canyon (Chestnut) and Mountain Side mines, and these mines then were operated by the Northern Pacific Coal Co. In 1902 the Northern Pacific Coal Co. was incorporated in the Northwestern Improvement Co., also a subsidiary of the Northern Pacific Railway Co.

DESCRIPTION OF MINES

COKEDALE DISTRICT

The Cokedale No. 1 mines were developed concurrently with the early Timberline mines and the Rocky Canyon mine at Chestnut. The community of Cokedale, in the western part of Park County—sec. 26, T. 2 S., R. 8 E., 9 miles west of Livingston—grew rapidly,

TABLE 6.—*Total recorded coal production, in short tons, and value in Gallatin and Park Counties, Mont.*

[Reference: MIM, Montana Inspector of Mines; USGS, U.S. Geol. Survey; USBM, U.S. Bur. Mines]

Year	Gallatin County[1]		Park County		Total		Reference
	Production	Value	Production	Value	Production	Value	
1883[2]	19,695		(1)		19,695		USGS (1886, p. 39).
1884	63,670		(1)		63,670		Do.
1885	83,865		(1)		83,865		Do.
1886	45,446		(1)		45,446		USGS (1888, p. 276).
1887	7,802		(1)		7,802		Do.
1888	24,867		(1)		24,867		USGS (1890, p. 291).
1889	43,838	$104,377	147,300	$421,950	191,138	$526,327	USGS (1892, p. 228).
1890	51,452	119,084	252,737	690,870	304,189	809,954	Do.
1891	56,981	135,893	285,745	692,570	342,726	828,463	USGS (1893, p. 269).
1892	61,198	152,496	258,991	684,473	320,189	836,969	USGS (1893, p. 436).
1893	63,163	148,021	306,526	691,816	369,689	839,837	USGS (1894, p. 321).
1894	69,257	168,431	214,253	463,394	283,510	631,825	USGS (1896, p. 147).
1895	98,398	204,122	503,200	1,099,075	601,598	1,303,197	USGS (1897, p. 552).
1896	108,460	214,535	93,132	147,875	201,592	362,410	Do.
1897	132,413	223,024	122,889	294,072	255,302	517,096	USGS (1899, p. 441).
1898	63,626	102,712	147,154	284,970	210,780	387,682	Do.
1899	56,671	84,961	128,850	262,062	185,521	347,023	USGS (1901, p. 469–470).
1900	51,671	84,472	86,025	255,700	137,696	340,172	USGS (1901, p. 407).
1901	24,583		77,981	144,254	102,564	144,254	USGS (1904, 396–398).
1902	88,000		89,640	189,080	177,640	189,080	Do.
1903	58,696		86,044	258,132	144,740	258,132	USGS (1905, p. 514–515).
1904	109,556		78,646	227,226	188,202	227,226	Do.
1905	123,006		81,807	241,463	204,813	241,463	USGS (1907, p. 696).
1906	97,926		102,339	287,520	200,265	287,520	Do.
1907	79,106		102,555	381,940	181,661	381,940	MIM (1909, p. 27); USGS (1909 p. 140).
1908	29,653		106,942	343,760	136,595	343,760	MIM (1909, p. 32); USGS (1909, p. 140).
1909	16,771		139,464	282,517	156,235	282,517	USGS (1911, p. 156–157).
1910	22,465		98,434	211,655	120,899	211,655	Do.
1911	8,515		46,333		54,848		USGS (1913, p. 160).
1912	1,406		44,626		46,032		Do.
1913	(3)		21,126		21,126		USGS (1916, p. 699).
1914	(3)		21,472		21,472		Do.
1915	(3)		(3)				USBM (written commun., 1958).
1916	(3)		4,000		4,000		Do.
1917	(3)		(3)				Do.
1918	(3)		(3)				Do.
1919	3,000		(3)		3,000		Do.
1920	8,000		240		8,240		Do.
1921	807		228		1,035		Do.
1922	115		(3)		115		Do.
1923	29		(3)		29		Do.
1924	4,000		(3)		4,000		Do.
1925	4,000		(3)		4,000		Do.
1926–31	(3)		(3)				Do.
1932	(3)		1,991	4,002	1,991	4,002	Do.
1933	(3)		(3)				Do.
1934	1,000	3,000	800	2,000	1,800	5,000	Do.
1935	(3)		(3)				Do.
1936	210	298	104	499	314	797	Do.
1937	(3)		(3)				Do.
1938	2,693		1,502		4,195		Do.
1939	1,217	3,651	3,019	8,695	4,236	12,346	Do.
1940	(3)		2,327	7,516	2,327	7,516	Do.
1941	1,206	3,485	1,988	7,137	3,194	10,622	Do.
1942	(3)		1,338	2,713	1,338	2,713	Do.
1943–64	(3)		(3)				Do.
Total	1,788,433		3,661,748		5,450,181		

[1] Gallatin County, Mont., established in 1865, was divided into Gallatin and Park Counties in 1887. Coal production from mines at Cokedale and Timberline was listed under Gallatin County prior to 1889. Production figures for mines near Gardiner, Mont., are included in, and could not be separated from, Park County statistics.

[2] Prior to 1882 mining activity was limited to development of mines and to mining small amounts of coal for local domestic use. Rocky Canyon Coal mine produced 224 tons in 1880 and a small amount in 1882 for use during construction of railroad tunnel at Bozeman Pass.

[3] No recorded production.

786-073 O-66—4

TABLE 7.—*Total recorded coke production, in short tons, in Gallatin and Park Counties, Mont., during 1889–1910*

[See table 6 for source of data for individual year]

Year	Gallatin County	Park County	Total
1889	----------	30, 576	30, 576
1890	----------	24, 000	24, 000
1891	858	27, 667	28, 525
1892	----------	36, 412	36, 412
1893	----------	57, 770	57, 770
1894	----------	36, 000	36, 000
1895	----------	19, 700	19, 700
1896	----------	79, 632	79, 632
1897	----------	100, 000	100, 000
1898	----------	128, 632	128, 632
1899	----------	83, 000	83, 000
1900	----------	74, 475	74, 475
1901	----------	65, 137	65, 137
1902	----------	60, 740	60, 740
1903	----------	62, 134	62, 134
1904	7, 000	47, 500	54, 500
1905	5, 000	68, 777	73, 777
1906	----------	69, 045	69, 045
1907	14, 074	60, 239	74, 313
1908	----------	59, 268	59, 268
1909	----------	82, 973	82, 973
1910	----------	37, 519	37, 519
Total	26, 932	1, 311, 196	1, 338, 128

FIGURE 8.—First coke oven in Montana, built in 1881 by W. H. Williams in the SE¼SW¼ sec. 24, T. 2 S., R. 8 E., Livingston coal field. The oven is made of blocks of sandstone from the Cokedale and Eagle Formations.

and in the 1890's rivaled Livingston in population. But the mines were short lived and by the turn of the century were abandoned. The town of Cokedale was deserted soon after.

The Cokedale Nos. 1 and 2 mines, secs. 21, 22, and 26, T. 2 S., R. 8 E., were the largest producers in the district. The Cokedale No. 1 mines were also among the largest in the Livingston coal field and were the largest producers of coke.

A pilot coke oven was built in 1881 by W. H. Williams in the SE¼SW¼ sec. 24, T. 2 S., R. 8 E., to test the coking qualities of the coal (fig. 8). Later, 40 beehive coke ovens were constructed at Cokedale, and by the time the mines were at maximum production, 115 ovens were in operation. A good grade of coke was produced from the Cokedale coal bed (table 2) until the Cokedale No. 1 mines closed about 1896.

COKEDALE NO. 1 MINES

Mining operations at the Cokedale No. 1 mines were started by W. H. Williams in about 1881, and commercial production began in 1883. In 1885 Williams sold his interest to V. E. Tull, who, in turn, sold the property to Samuel Hauser in 1888. The Livingston Coal and Coke Co., formed by Hauser, operated the mines until about 1896, when the failure of of the First National Bank of Helena caused the company to close the mines. The arrangement of the mines, coal-car tramway, tipple, washing plant, and coke ovens at Cokedale is shown in figure 9.

The mines were first opened with a horizontal drift 1,500 feet east of the NW cor. sec. 26, T. 2 S., R. 8 E. (pl. 1). The tunnel was only 600–700 feet long when the Livingston Coal and Coke Co. began an inclined shaft about 300 feet west of the portal. This shaft. which is adjacent to measured coal section 54 (pl. 1), was driven down the 40° northward dip of the Cokedale coal bed. Rooms or chutes were mined adjacent to the shaft from the first level to a depth of about 300 feet, at which point the shaft entered sec. 23.

The second level was started westward at a depth of 226 feet and was developed into sec. 22; an eastern extension of the level did not progress far before broken and faulted coal was penetrated, and further work in that direction was abandoned. After the second level had been driven a considerable distance westward, the incline was extended an additional 362 feet in depth, and the third level was driven westward through sec. 23 and a considerable distance into sec. 22. The fourth level was 286 feet below the third, and the fifth level was 386 feet below the fourth. The first through fourth levels were mined out for a distance of 5,555 feet west of the incline and for about 800 feet east of the incline. The fifth level, at a depth of 1,260 feet, was not developed.

The dip of the rocks at the surface is 40°, but it decreases gradually downward to 34° at the No. 1 level; the average dip between the Nos. 1 and 2 levels is 34°; between the Nos. 2 and 3 levels, 42°; between the Nos. 3 and 4 levels, 42°; and between the Nos. 4 and 5 levels, 40°. At the No. 5 level the dip flattens and averages 20°.

In the two lower levels west of the incline, several faults were discovered whose effects, in the form of rolls, were noticeable in the upper levels. The displacements were small and caused no trouble in mining. East of the incline, very little development was done at any level, as the coal had been badly broken by faulting.

Widely spaced crosscut tunnels on several levels west of the incline were developed southward to penetrate the Paddy Miles bed and the underlying Storrs No. 3 bed. The coal in these beds would coke, but the beds were not thick enough to be mined profitably.

The Andrew Miller prospect, in the NE¼ sec. 26, T. 2 S., R. 8 E., is a horizontal drift driven westward along the strike of the Cokedale bed to connect with the workings of the Cokedale No. 1 mines; however, the prospect was abandoned because the coal was thin, had many partings, and had been broken by faulting.

In 1889 the Cokedale No. 1 mines produced 49,400 tons of coal; 78 ovens produced 50 tons of coke per day, and 18 additional ovens were being repaired (Weed, 1891, p. 362). By 1892, mining at Cokedale was limited almost entirely to the Cokedale bed in three levels west of the main shaft at the Cokedale No. 1 mines, developed to a depth of 650 feet (Weed, 1892, p. 522).

Many pillars were mined from the lower levels during the middle 1890's in expectation of an end to mining operations. Then, about 1896, mining was discontinued, pumps were removed, and the workings became flooded.

During 1898–1900, Oscar James, of Spokane, Wash., leased the Cokedale No. 1 mines from the Livingston Coal and Coke Co. (or its creditors) and reopened the mines through the original incline. The water was pumped out, and the upper levels west of the incline were worked, mostly by pulling the remaining pillars. The coal was shipped, but no attempt was made to renew the coking operations. About 1902 the property was acquired by the Anaconda Copper Co., who dewatered the mines and made several developments, including a sixth level 300 feet below the No. 5 level (Montana Inspector of Mines, 1904, p. 24). The output in 1904 was 5,000–7,000 tons, all of which was used at Cokedale (Rowe, 1905, p. 247). The mine was abandoned in 1906 (Montana Inspector of Mines, 1906, p. 47).

The Cokedale bed was sampled at localities 54 and 55 (pl. 1) at the Cokedale No. 1 mines. Its stratigraphic relations and correlation are shown on plate 3, and analysis of a sample (No. 55) is given in table 2.

COKEDALE NO. 2 MINES

The Livingston Coal and Coke Co. developed several entries, known as the Cokedale No. 2 mines, west of and in conjunction with their Cokedale No. 1 mines. The No. 2 mines were used primarily for ventilation and safety exits for the No. 1 mines. Eldridge (1886, p. 781, 782) sampled the No. 2 mines in 1882.

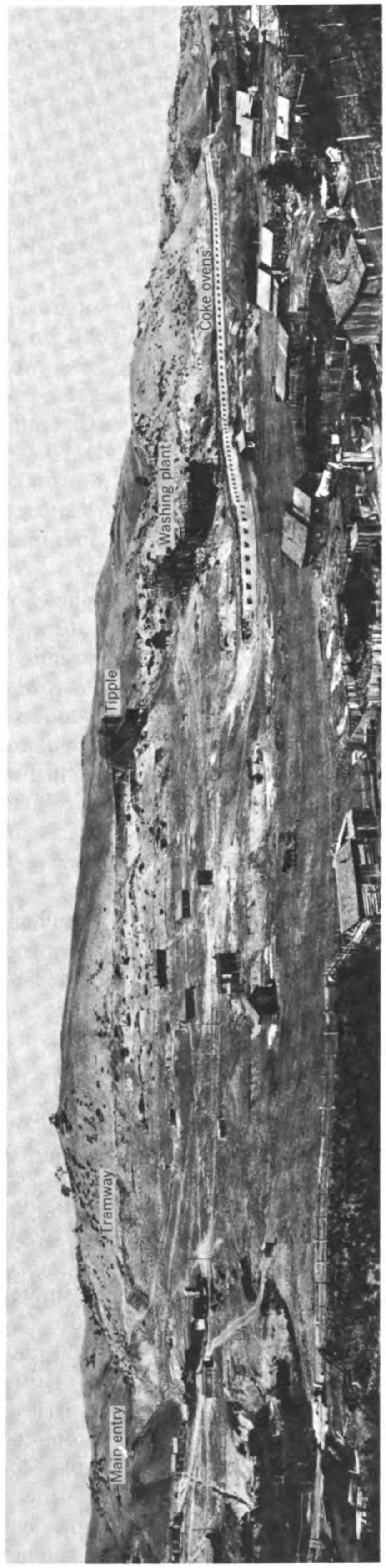


FIGURE 9.—Cokedale No. 1 mines, Livingston coal field. The main inclined shaft was immediately behind the mine dump (left side of photo.). The coal-car tramway from the shaft can be traced to the right to the tipple. Just below the tipple to the right is the washing plant, and below the washing plant are the coke ovens. Cokedale Spur of the Northern Pacific Railway Co. was adjacent to the coke ovens. Community of Cokedale was to the right of the area photographed. View north in sec. 26, T. 2 S., R. 8 E. Photographed by W. R. Calvert in 1908.

After removing the pillars from the Cokedale No. 1 mines, the Oscar James Co. made several new openings near those made by the Livingston Coal and Coke Co. The Oscar James Co.'s main development was a short horizontal drift driven eastward in the SW¼ sec. 22, T. 2 S., R. 8 E., to connect with the upper part of the rooms driven from the first level westward from the Cokedale No. 1 incline. Below the first level were the flooded old workings, so no attempt was made to develop the workings deeper.

Later the Oscar James Co. moved its operations farther west and drove a 280-foot inclined shaft on the Cokedale coal bed—about 300 feet west of the east line of sec. 21 and 900 feet north of the southeast corner of the section (pl. 6). This mine, known as the James entry, developed levels at depths of 80 and 280 feet; it extended eastward and intersected the upraises from the eastern works of the Cokedale No. 2 mines. A few hundred feet west of this new incline, small faults were discovered, and mining was discontinued.

The Cokedale No. 2 mines were worked by the Oscar James Co. for about 1 year, during which time all easily obtained coal, including the pillars, was removed to a depth of 280 feet, from the James entry eastward to the workings of the main Cokedale No. 1 mine. Output of about 20 tons per day was shipped to Spokane, Wash., where it was used by the Spokane Gas and Fuel Co. in the manufacture of gas. After the Oscar James Co. ceased work at these mines, the Northern Pacific Railway Co. removed its rails from the Cokedale spur.

The Cokedale bed was sampled at localities 25, 26, and 27 (pl. 1) at the Cokedale No. 2 mines. The bed's stratigraphic relations and correlation are shown on plate 3, and the analyses of two samples (Nos. 26, 27) are given in table 2.

NORTHERN PACIFIC COAL CO. MINE

An inclined shaft in the SW¼ sec. 24, T. 2 S., R. 8 E. (pl. 1), was begun in 1882 by the Northern Pacific Coal Co. Eldridge sampled this mine during 1882–83 at several levels and later (1886, p. 749, 782) very briefly described the coal bed's thickness in the mine. The incline was developed to a depth of 534 feet on the Cokedale bed, which dipped 37°–40°.

During a period of labor trouble in 1890, the portal was destroyed, and the mine was never reopened. Calvert (1912a, p. 393) visited the mine in 1908 and mentioned that there was an attempt at that time to reopen the mine with a new entry 500 feet westward along the strike; however, this entry was not completed. Calvert's (1912a, p. 402) location for his sample 6596 from this second entry is incorrect; it should be in the SW¼SW¼ sec. 24, T. 2 S., R. 8 E. The 31-inch coal bed which he sampled at the face 100 feet from the new portal was probably the Paddy Miles bed. The 2-foot coal bed above the sampled bed (Calvert, 1912a, p. 393) would then be the Cokedale; and the third bed, 30 feet above the Cokedale, would be a coal in the lower part of the Cokedale Formation (pl. 3).

The Cokedale bed was sampled at localities 56, 56a, and 57–62 (pl. 1) at (or in) the Northern Pacific Coal Co. mine. The bed's stratigraphic relations and correlation are shown on plate 3, and the analyses of five samples (Nos. 56, 57, 59–61) are given in table 2.

DALY PROSPECT

In 1892 Marcus Daly sank an inclined shaft on the Cokedale bed in the NE¼ sec. 30, T. 2 S., R. 9 E. (pl. 1). The incline was developed to a depth of 150 feet before being abandoned the same year. The coal from the top to the bottom of this incline was uniform and was similar to that in the bed at Cokedale; however, it was less suitable for coking.

SULPHUR FLATS MINE AND FRANK AND HILSON PROSPECTS

In sec. 29, T. 2 S., R. 9 E., coal is indicated in many places by abandoned mine or prospect dumps; however, little information is available regarding them. The Sulphur Flats mine in the center of sec. 29 (pl. 1) was reported by L. E. Williams (oral commun., 1957) to produce about 6–8 tons of coal per day, which was sold for domestic use in Livingston. G. Bowers developed the mine about 1906. The Frank prospect in the NW¼ was an inclined shaft on the Cokedale bed (pl. 1). This shaft was developed by H. L. Frank to a depth of about 100 feet and was abandoned prior to 1901. In 1912 Cleveland Hilson made an incline, which he named the Peacock mine, on the Cokedale bed in the NE¼ sec. 29, T. 2 S., R. 9 E. (pl. 1). The prospect was abandoned at a depth of 60 feet the same year. Hilson reported the Cokedale bed to be 4–5½ feet thick, including two partings, and to contain about 2½ feet of merchantable coal.

SPANGLER AND KANGLEY MINES

Very little is known about these mines, which are in sec. 29, T. 2 S., R. 9 E. (pl. 1). They were small producers for domestic trade. The Spangler mine was an inclined shaft developed by Joe Spangler in 1883 on the Cokedale bed, and the Kangley mine was a horizontal drift that trended westward along the strike of the Cokedale bed.

The Cokedale bed was sampled at locality 66 (pl. 1) at the Kangley mine; the bed's stratigraphic relations and correlation are shown on plate 3, and the analysis of a sampler (No. 66) is given in table 2.

WILLIAMS MINE

The Williams mine, in the NE¼ sec. 27, T. 2 S., R. 9 E., is the easternmost mine in the Cokedale district (pl. 1). This mine, developed by W. H. and Thomas Williams, was a small producer of domestic coal sold in Livingston during the 1930's. The mine was a horizontal drift developed westward on the strike of the Big Dirty bed, which, at that locality, dips 35° NW. The bed contained many partings (see measured section 2) and the coal was badly broken.

The stratigraphic relations and correlations of the Big Dirty bed at the portal of the Williams mine at locality 67 (pl. 1) are shown on plate 3.

HUBBARD MINE

In 1920–21 the Hubbard mine, in the SE¼ sec. 21, T. 2 S., R. 8 E. (pl. 1), was developed in the Middle bed, known locally as the Cokedale No. 3 bed (pl. 3). The main haulageway extended 930 feet along the strike of this bed (pl. 6). Near the west end of the level and 850 feet in from the portal, a crosscut rock tunnel was started northward in 1924 in an effort to reach the thicker Cokedale bed; however, after only 35 feet of sandstone had been cut, work was discontinued.

Approximately 3,000 tons of coal was mined before the operation was abandoned in 1925. A considerable part of this total was left on the dump.

An analysis of the coal bed at the Hubbard mine is given in table 2.

COKEDALE NO. 3 MINE

In 1934 Llewellyn and Thomas Williams, sons of the W. H. Williams who started mining at Cokedale, developed the Cokedale No. 3 mine in the SW¼ sec. 22, T. 2 S., R. 8 E. (pl. 1). The mine was entered by a 20-foot rock tunnel and was developed from an inclined shaft on the Middle bed—known locally as the Cokedale No. 3 bed—on a combination of stall and room-and-pillar systems with no specific spacing. The mine produced small amounts of coal for domestic use for approximately 2 years before it was closed.

The stratigraphic relations and correlations of the Middle bed in the Cokedale No. 3 mine, locality 8 (pl. 1), are shown on plate 3, and the analysis of a sample (No. 29) is given in table 2.

BUCKSKIN AND JOHNSON MINES

These two small mines at the west end of the Cokedale district, in the SW¼ and NW¼ sec. 28, T. 2 S., R. 8 E. (pl. 1), were horizontal drifts southward along the strike of the Cokedale bed. Production, which was small, was for domestic use in Livingston. The Buckskin mine was developed in 1888 by Joseph McKeown and was sold in 1889 to the Livingston Coal and Coke Co. Gus Johnson opened the Johnson mine about 1906.

The stratigraphic relations and correlations of the Cokedale bed in the Buckskin and Johnson mines, localities 52 and 53 (pl. 1), are shown on plate 3.

McCORMICK PROSPECT

One of the latest efforts to revive coal mining in the Livingston coal field was by E. B. McCormick in 1955. He drove a horizontal drift eastward along the strike of the Middle bed in the SW¼ sec. 22, T. 2 S., R. 8 E. The prospect was abandoned in 1956.

The stratigraphic relations and correlations of the Middle bed at the McCormick prospect, locality 28 (pl. 1), are shown on plate 3.

TIMBERLINE DISTRICT

C. W. Thompson began development in this district in 1881 for the Northern Pacific Coal Co. A narrow-gage railroad between Timberline and West End was completed in 1883, and during that year coal shipments totaled 10,489 tons. The coal was used exclusively for locomotive fuel by the Northern Pacific Railway Co. on the run from Glendive, Mont., to Sprague, Wash. Production totaled 55,664 tons in 1884, 83,156 tons in 1885, 45,446 tons in 1886 (although the mines were idled by labor strikes during much of 1886), 7,802 tons in 1887, 24,867 tons in 1888, and 43,838 tons in 1889 (U.S. Geol. Survey, 1887, p. 275; Weed, 1891, p. 362). During 1882–83 Eldridge (1886, p. 781–782) took samples from many of these mines and prospects.

C. W. Hoffman leased the Timberline mines in 1888 and operated them through 1895. During 1891–95 the Timberline Nos. 3, 5, and 6 mines employed about 125 men, who mined about 5,000 tons of coal per month (Montana Inspector of Mines, 1891, 1895).

In 1895, after the readily available coal had been removed, the Timberline mines were closed because the continuation of mining would have required many expensive improvements. Hoffman then moved from Timberline to Trail Creek and purchased the Mountain House mine.

During the first brief period of mining in this district, a sizable community known as Timberline was established along Timberline Creek in secs. 23–25. At peak production of the Timberline No. 3 mine, more than 300 miners and their families lived in this small valley. Calamity Jane, one of the more enterprising residents during the growth of this community, maintained a strategically located log cabin near Craig's Cut, just west of the Timberline No. 3 mine.

The Q and H Nos. 1 and 2 mines and the Hyer, Dunn, Thompson, Brady, and Palmer and Ryan prospects were all closed by the time the Timberline mines suspended operations in 1895. The miners and their families moved to other districts, and the community of Timberline was abandoned. Activity was resumed in the 1930's with the development of the Woodland, Ross, Pendleton, DiLulo, and Number Thirty mines and the reopening of the Timberline No. 6 mine; however, production was small and mining activities were short lived.

TIMBERLINE NO. 1 MINE

The Timberline No. 1 mine was a horizontal drift driven westward on the Cokedale bed by the Northwest Improvement Co. about 1881. The portal was 1,600 feet west and 800 feet north from the SE cor. sec. 24, T. 2 S., R. 7 E. (pl. 1). The coal bed dips 52° NE.; and, according to Eldri 'ge (1886, p. 749), it had fewer and smaller partings than did the bed at prospects and mines to the south. The workings extended approximately 600 feet westward, and the last recorded depth was 232 feet (Eldridge, 1886, p. 749). An inclined shaft was also developed immediately east of the water-level entry.

The Cokedale bed was sampled at localities 15–19 (pl. 1) in the Timberline No. 1 mine. The bed's stratigraphic relations and correlation are shown on plate 3, and analyses of five samples (Nos. 15–19) are given in table 2.

TIMBERLINE NO. 2 MINE

The Timberline No. 2 mine, in the SE¼ sec. 24, T. 2 S., R. 7 E. (pl. 1), was a horizontal drift driven eastward on the Cokedale bed. The portal was 200 feet east of the No. 1 portal. The workings extended 500 feet east and dipped 53°. The coal in this mine contained very few partings (pl. 3).

The stratigraphic relations and correlations of the Cokedale bed in the Timberline No. 2 mine, locality 20 (pl. 1), are shown on plate 3.

TIMBERLINE NO. 3 MINE

The Timberline No. 3 mine, in the central part of the S½ sec. 23, T. 2 S., R. 7 E. (pl. 1), was by far the largest producer in the Timberline district and was one of the largest in the Livingston coal field. The mine was started with a horizontal entry on the Cokedale bed 2,650 feet east and 1,175 feet north of the SW cor. sec. 23. This tunnel extended eastward into the NE¼ sec. 23, and a 30° incline was developed near the portal. By 1891 the first level was down 280 feet, and work was continuing on a second level 250 feet below the first (Montana Inspector of Mines, 1891). The main incline was 900 feet deep by 1895 (Montana Inspector of Mines, 1895). During this development a small amount of coal was produced from the Paddy Miles bed.

Daily production from this mine during 1885–95 averaged 300 tons; however, it declined to 200 tons near the end of this period (Montana Inspector of Mines, 1895). The mine closed in 1895.

Warm sulfur-bearing springs are present in this mine. The pungent odor of the water caused local residents to call the mine the Stinking Water mine, and it is thus designated on the U.S. Geological Survey topographic map of the Bozeman Pass quadrangle, published in 1957. This water now flows from the former air tunnel of the No. 3 mine.

In 1940 Henry Merrick tried to reopen the No. 3 mine by opening the old portal. He mined a few pillars and then abandoned his venture.

The stratigraphic relations and correlations of the Cokedale bed in the Timberline No. 3 mine, locality 11 (pl. 1), are shown on plate 3.

TIMBERLINE NO. 4 MINE

The Timberline No. 4 was a rock tunnel 50 feet south and 1,775 feet west of the SE cor. sec. 25, T. 2 S., R. 7 E. (pl. 1). The tunnel was dug about 1894 and extended north 850 feet to a point where it joined the lower workings of the Timberline No. 1 and 2 mines. It was then used as a haulageway for these mines.

TIMBERLINE NO. 5 MINE

The Timberline No. 5 was a rock tunnel 1,975 feet east and 350 feet north of the SW cor. sec. 24, T. 2 S., R. 7 E. (pl. 1). This tunnel extended 1,800 feet north to intersect the Cokedale bed and was intended as a haulageway for the Timberline No. 3 mine workings when this point was reached; however, the mines were closed before the haulageway was completed. During the 1930's Frank Woodland and Ray Ross reopened 1,300 feet of the tunnel in a second unsuccessful attempt to develop the No. 5 mine.

TIMBERLINE NO. 6 MINE

The Timberline No. 6 mine was opened by the Northern Pacific Coal Co. about 1881 in the NE¼ sec. 25, T. 2 S., R. 7 E., and the NW¼ sec. 30, T. 2 S., R. 8 E. (pl. 1). Eldridge (1886, p. 781–782) sampled this mine during 1882–83. The mine was developed by a rock tunnel that had horizontal entries on the Cokedale bed, normal to the tunnel (pl. 7). The coal bed dips 79° E. The mine was worked to a depth of 300 feet by the Northern Pacific Coal Co. before being closed. The Cokedale bed at this locality contains many partings, and the coal required washing. Three levels were mined by use of a room-and-pillar system for about 500 feet along the strike and to a depth of 40 feet. Production was small and was recorded along with that from the company's other mines at Timberline.

Tom Coulston reopened the Timberline No. 6 mine in 1933. During the next 3 years he developed a fourth level, at a depth of 60 feet, and also mined many of the pillars in the older workings. Since 1933 the mine has been known as the Coulston mine. The coal was sold for local domestic use.

The Cokedale bed was sampled at localities 45–48 (pl. 1) in the Timberline No. 6 mine. The bed's stratigraphic relations and correlation are shown on plate 3, and the analyses of three samples (Nos. 45–47) are given in table 2.

Q AND H NOS. 1 AND 2 MINES

During the 1880's P. J. Quealy and C. W. Hoffman operated the Q and H Nos. 1 and 2 mines at Timberline in the SW¼ sec. 23, T. 2 S., R. 7 E. (pl. 1). These were horizontal drifts driven southward along the strike of the Cokedale bed. The Q and H No. 2 mine was 300 feet above the Q and H No. 1 mine. It was reached by a double-track incline railroad 440 feet long, up which the empty cars were hauled by the weight of the loaded ones going down (Avant Courier, Feb. 19, 1885). The No. 2 mine was 800 feet long, and the rooms from which the coal was mined were 250 feet high. The No. 1 mine was about 900 feet long. The entire output of the mines was sold to the Northern Pacific Railway Co. Mining was suspended in July 1888, when C. W. Hoffman leased the Timberline mines (Avant Courier, July 12, 1888).

WOODLAND MINE

The Woodland mine was a horizontal drift driven eastward 800 feet on the Cokedale bed. The entry, 1,450 feet north and 3,500 feet west of the SE cor. sec. 24, T. 2 S., R. 7 E. (pl. 1), was opened in 1935 by Frank Woodland. In 1938 a slope was made near the portal, and a second level 50 feet below the first was developed (pl. 7); the second level had been extended 300 feet eastward before the mine was closed in 1943.

The Cokedale bed was 8 feet thick in the mine and was very similar in many respects to the bed in the Ross mine (pl. 3). Only the upper 2½ feet of the bed could be marketed, because there was no washing plant. The beds dipped 43°–59° N. Mining was done by the room-and-pillar system with no specific spacing. Production was small and was sold for domestic use.

ROSS MINE

The Ross mine was a 150-foot inclined shaft from which three levels were driven eastward on the Cokedale bed. The portal, 1,465 feet north and 2,700 feet west from the SE cor. sec. 24, T. 2 S., R. 7 E. (pl. 1), was opened by Ray Ross in 1934. The first and second levels extended 750 feet eastward and were mined to the surface (pl. 7). The third level had been mined 220 feet eastward before the mine was closed in 1941.

The Cokedale bed was 8 feet thick, had many partings (pl. 3), and dipped 49°–56° NE. Mining was done by the room-and-pillar system with no specific spacing. Production was small and was sold in Bozeman for domestic fuel.

The stratigraphic relations and correlation of the Cokedale bed in the Ross mine, locality 12 (pl. 1), are shown on plate 3.

PENDLETON MINE

The Pendleton mine was a horizontal drift driven northward on the Cokedale bed. The portal was 975 feet north and 1,650 feet west from the SE cor. sec. 24, T. 2 S., R. 7 E., just north of the Timberline No. 1 mine (pl. 1). The mine was opened in 1943 by H. D. Pendleton and was developed 390 feet into the hill before it was closed in 1947 (pl. 7). The mine workings were a modified room-and-pillar system with 45-foot centers. Production was very small.

The stratigraphic relations and correlation of the Cokedale bed in the Pendleton mine, localities 13 and 14 (pl. 1), are shown on plate 3.

HYER PROSPECT

The Hyer prospect was an inclined shaft on the Cokedale bed in the NE¼ sec. 25, T. 2 S., R. 7 E. (pl. 1). Eldridge (1886, p. 782) sampled this incline in 1883. No production is reported from this prospect.

The Cokedale bed was sampled at localities 43 and 44 (pl. 1) in the Hyer prospect. Its stratigraphic relations and correlation are shown on plate 3, and the analysis of a sample is given in table 2.

DUNN AND THOMPSON PROSPECTS

The Dunn and Thompson prospects, in the NW¼ sec. 30, T. 2 S., R. 8 E. (pl. 1), were opened on the Cokedale bed in the early 1880's. No production is reported from these prospects.

The stratigraphic relations and correlation of the Cokedale bed at the Dunn and Thompson prospects, localities 49 and 50 (pl. 1), are shown on plate 3.

NUMBER THIRTY MINE

The Northern Pacific Coal Co. opened the Number Thirty mine by means of a horizontal drift driven southeast along the strike of the Cokedale bed in the SW¼ sec. 30, T. 2 S., R. 8 E. (pl. 1). The tunnel had been extended about 500 feet from the portal before the mine was abandoned. The date of this period of development is not known. Production was small and was incorporated with the company's production from other mines at Timberline. The mine was named for the section in which it was located.

Frank Woodland and Ray Ross reopened the mine in 1932. Three shafts were driven from the original tunnel, and a second level was developed 25 feet below the original tunnel. The second level was driven 600 feet southward before the mine was closed in 1934. The coal bed was thick at this locality (pl. 3), but it contained many partings that were difficult to separate without a washing plant. Mining was done by the room-and-pillar system with 50-foot centers. The coal bed dips 86° E.

The stratigraphic relations and correlation of the Cokedale bed in the Number Thirty mine, locality 50 (pl. 1), are shown on plate 3.

DILULO MINE

In 1933 Mike DiLulo opened a horizontal drift on the Cokedale bed in the NE¼ sec. 31, T. 2 S., R. 8 E. (pl. 1). The mine was developed 480 feet northward along the strike of the coal bed, which dips 55°–85° E., by the room-and-pillar system with 25-foot centers. The mine operated until 1937, and the production, which was small, was sold locally for domestic use. Coal from this mine was of coking quality.

The stratigraphic relations and correlation of the Cokedale bed in the DiLulo mine, locality 68 (pl. 1), are shown on plate 3.

BRADY NO. 1 AND 2 PROSPECTS AND PALMER AND RYAN PROSPECT

Very little information is available regarding the coal prospects in sec. 32, T. 2 S., R. 8 E. (pl. 1). Eldridge (1886, p. 781–782) sampled them during 1882 and 1883, but no production is reported from these workings.

The stratigraphic relations and correlation of the Cokedale bed at the Brady Nos. 1 and 2 prospects and at the Palmer and Ryan prospect, localities 70, 71, and 75 (pl. 1), are shown on plate 3.

MEADOW CREEK DISTRICT

Many mines were developed in the Meadow Creek district, including the Rocky Canyon and the Mountain Side mines, which became two of the largest producers in the Livingston coal field. The Rocky Canyon mine was the first commercial mine in Montana (McDonald and Burlingame, 1956, p. 24); its development stimulated growth of the nearby community of Chestnut. The later development of the Mountain Side mine extended the growth of Chestnut for an additional decade. Most of the production was consumed as locomotive fuel by the Northern Pacific Railway Co.

ROCKY CANYON (CHESTNUT) MINE

Coal was discovered in the Livingston coal field in 1867 by two blacksmiths from Bozeman. Col. James D. Chesnut, hearing of the discovery, offered to furnish provisions to men who would work the coal bed, if the men would give him a share of the property. This scheme was so successful that, later, Colonel Chesnut became the sole owner of the claim (A. C. Peale, in Hayden, 1873, p. 113), which he developed as the Rocky Canyon coal mine. Colonel Chesnut's colorful career and his influence on the young community of Bozeman was presented in detail and documented by McDonald and Burlingame (1956).

Colonel Chesnut drove a horizontal drift, which by 1871 was 180 feet long (Hayden, 1872, p. 46) and by 1872 was 250 feet long (A. C. Peale, in Hayden, 1873, p. 113). Through 1879 the mine had produced 1,344 tons of coal, which was sold at Fort Ellis and Bozeman for domestic use. Production during 1880 was 224 tons (U.S. Dept. Interior, 1886, p. 899).

By 1881 Colonel Chesnut had developed two parallel horizontal drifts driven northwestward 150 and 500 feet along the strike of the Cokedale coal bed (known locally as the Chestnut bed). The bed dipped 60°-86° NE. The portals were in the NW¼SW¼ sec. 21, T. 2 S., R. 7 E. (pl. 1).

The Rocky Canyon mine was worked by Col. James Muir during the fall and winter of 1882–83 to supply coal for the operation of the large steam engines used in constructing the Northern Pacific Railway Co. tunnel through Bozeman Pass.

In 1882 F. D. Pease and C. W. Hoffman filed claims to land adjacent to the Rocky Canyon coal mine, and went into partnership with Colonel Chesnut. D. F. Sherman, C. H. Cobb, and Frank Esler bought Colonel Chesnut's one-third interest in the mine and property in 1883, and, with Pease and Hoffman, formed the Bozeman Coal Co. and contracted to furnish to the Northern Pacific Railway Co. the entire output of coal for the next 5 years (Avant Courier, June 28, 1883). Within a few months, however, the Northern Pacific Railway Co. got the Timberline mines into production, and little coal was taken out of the Rocky Canyon mine in 1883 compared with that taken from the Timberline mines.

By September 1883 the two main drifts had been developed 900 and 1,100 feet along the strike of the Cokedale bed. Sixty to seventy-five men were employed, and the output was 80–100 tons per day. The Bozeman Coal Co. made a new entry on the Cokedale bed in the center of the N½N½ sec. 20, T. 2 S., R. 7 E., in November 1883 and built a tramway from this entry southward one-half mile to the railroad (pl. 8).

The contract with the Northern Pacific Railway Co. was voided in 1884 when the Bozeman Coal Co. sold its property to the Union Pacific Railroad Co. At that time the Union Pacific Railroad Co. contemplated building a branch line from Bozeman to Butte and coking the coal of the Rocky Canyon mine for use in the smelters at Butte. The Union Pacific Railroad Co. had previously purchased the Maxey mine, and both mines were taken out of production while the coking quality of the coal was being tested. The tests proved the coal to be only partly coking in character, and the proposed branch line was not built.

Production from the Rocky Canyon mine in 1883 was 8,970 tons; in 1884, 7,612 tons; and in 1885, 100 tons (U.S. Geol. Survey, 1885, p. 38). The mine was closed in 1885.

Frank Esler reopened the mine in 1887 under a lease from the Union Pacific Railroad Co. He operated the mine for several years, employing about 40 miners, until the Northern Pacific Railway Co. acquired the property about 1891. The Northern Pacific Railway Co. leased the mine to J. C. McCarthy and J. A. Johnson, who operated it until 1902. The property was then transferred to the Northwestern Improvement Co., a subsidiary of the Northern Pacific Railway Co. The mine was operated by this company until about 1906, when it was again closed (Calvert, 1912a, p. 398) and never reopened for commercial production. Plate 8 shows the extent of these underground workings. The mine became best known during this time as the Chestnut mine, and the name Rocky Canyon has all but been forgotten.

With the development of prospects and mines near the Rocky Canyon mine, a community grew in the center of sec. 20, T. 2. S., R. 7 E. Colonel Chesnut spelled his name as written here; but the name on the post office in this community was misspelled as Chestnut, and the misspelled name prevailed. Eldridge (1886, p. 781) and Calvert (1912a, p. 397) referred to the mine as the Chestnut mine. During the period when the mines were owned by the Bozeman Coal Co., the mines were known as the Bozeman mines.

By 1895 the main tunnel extended 2,000 feet from the portal, and the mine employed 80 men (Montana Inspector of Mines, 1895). The mine produced 240 tons of coal daily. By 1897 the mine was being developed through two tunnels: No. 1, 5,500 feet long; and No. 2, 4,500 feet long (Montana Inspector of Mines, 1897). The mine employed 150 men underground and 15 men on the surface at that time and production averaged 350 tons per day. The length of the main drift by 1900 was 10,000 feet, but the mine employed only 75 men (Montana Inspector of Mines, 1900). By 1901 the workings of the Rocky Canyon coal mine included all of the Cokedale bed above the main water-level drift through secs. 17, 18, 20, and 21, T. 2 S., R. 7 E. (pl. 8), and at this time the operators began sinking a shaft to develop a lower level.

In 1902 the Northwestern Improvement Co. assumed operation of the Chestnut mine and also acquired the Mountain Side mine (Montana Inspector of Mines, 1904). Operations of the two mines were then combined, and a horizontal drift was cut to connect their main workings (pl. 8).

The total production of the Rocky Canyon (Chestnut) mine from 1882 through 1902 was 565,000 tons. During 1903–7 production was recorded with that of the Mountain Side mine. An analysis of the coal is given in table 2.

The Cokedale bed was sampled at localities 5 and 6 (pl. 1) at the Rocky Canyon (Chestnut) mine. The bed's stratigraphic relations and correlation are shown on plate 4.

MAXEY MINE

In 1881, Daniel Maxey, a western Montana pioneer, opened the Maxey mine—a horizontal drift driven southward on the strike of the Cokedale bed—on the south side of Rocky Canyon in the SW¼ sec. 21, T. 2 S., R. 7 E. (pl. 8), and by 1882 the mine was supplying coal for domestic needs in Bozeman (Avant Courier, Dec. 1, 1881; Nov. 30, 1882). Production was 236 tons in 1883 and 394 tons in 1884; no coal was produced in 1885 (U.S. Geol. Survey, 1885, p. 39).

In 1884 the Utah and Northern Railroad Co., a subsidiary of the Union Pacific Railroad Co., purchased the Maxey mine. The Utah and Northern Railroad carried large quantities of coke from Utah to the copper smelters in Butte, and the officials of the railroad company decided to manufacture coke at this closer locality. Experiments on the coking qualities of coal from this mine and from the Rocky Canyon mine, which they had also acquired, were carried on for about 1 year. The results of the coking tests were discouraging, and the mine was closed in 1885.

MOUNTAIN SIDE MINE

The Maxey mine and its property were leased from the Union Pacific Railroad Co. in the late 1890's by the Mountain Side Coal Co. This company, under the direction of M. J. Johnson, began a new horizontal drift on the Cokedale bed from a portal just north of the older Maxey portal in the NE¼SW¼ sec. 21, T. 2 S., R. 7 E. (pls. 1, 8). The coal bed dipped 23°–60° NE. By 1900 the drift was 1,800 feet long southward and the mine employed 70 men (Montana Inspector of Mines, 1900). During 1901 the drift was extended an additional 1,200 feet southward, and areas to be mined were blocked out.

The Mountain Side mine was purchased by the Northern Pacific Railway Co. in 1902, and operations of the mine were combined with those of the Chestnut mine, under the supervision of the Northwestern Improvement Co. (Montana Inspector of Mines, 1905). A horizontal drift, connecting the main workings of the Chestnut and Mountain Side mines, was completed in 1903. An inclined shaft was then driven to a depth of 500 feet in the Mountain Side mine (Montana Inspector of Mines, 1904).

In the Mountain Side mine there were areas in sec. 21, T. 2 S., R. 7 E., where Tertiary diabase dikes intruded the coal-bearing rocks, and the Cokedale bed adjacent to the intrusives had been transformed to coke (pl. 8).

The exterior workings of the Mountain Side mine were up to date, and the mine was one of the best equipped in the Livingston coal field. The mine had an excellent tipple, a washing plant with a daily capacity of 600 tons of coal (fig. 10), hand-picking tables for removing the bone, and four large hoists (Rowe, 1908a, p. 15).

The following production data were taken from reports by the Montana Inspector of Mines (1906, 1909, 1910):

	Year	Tons produced	Men employed
Mountain Side and Rocky Canyon (Chestnut) mines combined	1903	43,224	200 (approx)
	1904	60,000–70,000	200 (approx)
	1905	124,380	161
	1906	86,175	125
	1907	64,128	162
Mountain Side mine	1908	29,191	174
	1909	8,117	17
	1910	15,672	32

All production from this mine was used by the Northern Pacific Railway Co. for locomotive fuel.

The stratigraphic relations and correlation of the Cokedale bed at locality 8 (pl. 1) in the Mountain Side mine are shown on plate 4, and an analysis of the coal is given in table 2.

THOMPSON NOS. 1 AND 2 PROSPECTS

The Thompson Nos. 1 and 2 open-pit prospects on the Cokedale bed in the NE¼ sec. 20, T. 2 S., R. 7 E. (pl. 1), were made in 1880 by C. W. Thompson. These prospects were dug to evaluate Colonel Chesnut's property for possible purchase by the Northern Pacific Railway Co. Eldridge (1886, pl. 63, secs. 1 and 2) sampled and described the coal in these pits in the early 1880's.

The Cokedale bed was sampled at localities 1 and 3 (pl. 1) at the Thompson Nos. 1 and 2 prospects. The bed's stratigraphic relations and correlation are shown on plate 4, and the analysis of a sample is given in table 2.

BAILEY AND BEADLE MINE

The Bailey and Beadle mine, in the SW¼ sec. 13, T. 2 S., R. 6 E. (pl. 1), was opened in the early 1900's by John Bailey and Joseph Beadle. The mine was a horizontal drift driven about 450 feet northeastward along the strike of the Cokedale bed, which at that locality dips 40°–50° NW. (pl. 6). The coal bed is 2½–3 feet thick where it is least disturbed and includes three distinct partings of bone 2–6 inches thick. Much of the coal is bony and badly broken. Many small faults cut the coal bed, and many minor irregularities are present in its roof and floor (Calvert, 1912a, p. 398). The mine produced only a small amount of coal, which

FIGURE 10.—Mountain Side mine, Livingston coal field. Main entry was just to the left of the three buildings shown in the center of the photograph. The largest building was the washing plant and tipple. Double tracks at right are those of the Northern Pacific Railway Co. The community of Chestnut was just behind the hill shown at the right side of the photograph. View toward the west; Chestnut Mountain is in background. Photographed by W. R. Calvert in 1908.

was sold to the ranchers in the nearby valley. The mine was closed in 1910.

Bailey and Beadle also opened several prospects in sec. 13. They drove a horizontal drift about 50 feet long 350 feet northeast of the mine portal, and another about 250 feet long 250 feet farther northeast.

An unnamed bed crops out near the mine and prospects, 40 feet stratigraphically above the Cokedale bed. The bed is 6 feet thick, including partings, but the abundant impurities preclude economic mining (Calvert, 1912a, p. 398).

The area was prospected again during 1929–31, and a small amount of coal was mined by D. Whitehead and B. Storey for domestic use.

An analysis of the coal bed at the Bailey and Beadle mine is given in table 2.

LASICH PROSPECT AND MINE

The Lasich prospect, in the NE¼NW¼ sec. 20, T. 2 S., R. 7 E. (pl. 1), was a horizontal drift driven north 682 feet on the strike of an unnamed bed by Steve Lasich during 1921–22. The bed contained 14–16 inches of clean coal and dipped almost vertically.

In 1924 Steve Lasich began development of the Lasich mine, in the N½SE¼ sec. 18, T. 2 S., R. 7 E. (pl. 1). The mine was a horizontal drift driven southeast on the strike of the Cokedale bed. The coal bed was thin and contained many partings. The mine, producing for the domestic trade in Bozeman, was operated on a small scale until 1934.

In the early 1930's, N. L. Rouse sank a prospect shaft on the Cokedale bed between the southern limits of the Lasich mine and the northern limits of the Rocky Canyon (Chestnut) mine. The coal bed dipped 83° NE. and was too thin to be mined.

During 1930–33 a prospect horizontal drift was driven southward 525 feet on the strike of an unnamed coal bed in the NE¼NW¼ sec. 20, T. 2 S., R. 7 E. (pl. 1), just southeast of the Lasich prospect. The bed was the same one that was found at the Lasich prospect.

MEADOW CREEK COAL CO. MINES

Daniel Maxey, after selling the Maxey mine in Rocky Creek Canyon in 1884, began development of a mine in sec. 28, T. 2 S., R. 7 E., which was later known as the Meadow Creek No. 3 mine (pls. 1, 5). It was developed on the Storrs No. 3 bed by two horizontal drifts, the longer of which was about 600 feet in length. Production was small and was sold for domestic use in Bozeman. Maxey operated this mine for only a few years and then moved to the Trail Creek coal district.

In 1918 the Maxey Bros. began a horizontal drift on the Storrs No. 3 bed a few hundred feet east of the Meadow Creek No. 3 mine. This tunnel was later known as the Meadow Creek No. 2 mine. Production by the Maxey Bros. was about 50 tons per day for about 1 year. The mine was taken over by the Meadow Creek Coal Co. and was their main producer for 3 years before it was abandoned in 1924.

In 1922 the Meadow Creek Coal Co. opened the Meadow Creek No. 1 mine, a small mine in the NW¼ sec. 27, T. 2 S., R. 7 E. (pl. 5), on the Cokedale bed. It was abandoned the same year because a large diabase dike (pl. 1) nearby limited the amount of accessible coal.

In the early 1930's, several mines were developed in the vicinity of the Meadow Creek mines. These included the Whitehead-Robinson, Harris-Murphy, Harris-Murphy-Rouse, and Miller Nos. 1, 2, and 3 mines. The Whitehead-Robinson mine (pl. 5) was the largest, and it operated from 1931 through 1942 for domestic trade. The Harris-Murphy mine (pl. 5) was a small lower level development in the Meadow Creek Coal Co. No. 2 mine. The Harris-Murphy-Rouse mine was opened in 1931 in an unsuccessful attempt to intersect the Storrs No. 3 coal bed. The Miller No. 1 mine (pl. 5) was developed by Carl and Edward Miller in 1926 on the Storrs No. 3 bed to supply the local domestic trade; it produced about 30 tons per day for about 5 months per year through 1933. The Miller No. 2 mine on the Cokedale bed and the Miller No. 3 mine on an unnamed bed stratigraphically beneath the Storrs No. 3 bed produced small quantities of coal which were sold for domestic use locally.

The stratigraphic relations and correlation of the Cokedale and Storrs No. 3 beds in the Meadow Creek Coal Co. mines, localities 37 and 38 (pl. 1), are shown on plate 4.

HODSON MINE

Enoch Hodson opened the Hodson mine, in the NW¼ sec. 35, T. 2 S., R. 7 E., in 1883 (pls. 1, 5). The mine was first opened by an inclined shaft, which was superseded in 1888 by a rock tunnel driven 650 feet across the strike to intercept the Cokedale bed 350 feet below the previous workings. Development was confined to the area northwest of the entry because a fault cuts the coal on the opposite side. The entry from the slope extended 900 feet along the strike, and rooms were opened above the entry. The bed here dips 35° NE.

The mine was operated intermittently by Hodson, who generally employed less than 10 miners. Production was small and for local trade. By 1902 the property had been acquired by the Washoe Coal Co.; however, this company did not continue development of the mine.

In 1908 the property was under lease to J. D. Evans; and at the time of examination by Calvert (1912a,

p. 395), the mine had been put in operating condition. Nine men mined 6,950 tons of coal in 1909, and 12 men mined 6,073 tons of coal in 1910 (Montana Inspector of Mines, 1910). A section of the coal bed was described by Calvert (1912a, p. 395), who incorrectly identified this mine as the Washoe No. 1. According to Calvert (1912a, p. 396), the mine was abandoned in 1910.

The Cokedale bed was sampled at locality 42 (pl. 1) in the Hodson mine. The bed's stratigraphic relation and correlation are shown on plate 4, and the analysis of a sample is given in table 2.

WASHOE COAL CO. NOS. 1, 2, 3, AND 4 MINES

A Northern Pacific Railway Co. field party, under the direction of L. S. Storrs, prospected the coal-bearing rocks in the valley of Meadow Creek in 1901. This work was done for the Anaconda Copper Co. for the purpose of developing mines to produce coking-quality coal. In 1902 Anaconda—through a subsidiary, the Washoe Coal Co.—acquired the property and began development of the mines and construction of a large and elaborate washing plant, coke ovens, Goose Creek reservoir, and the community of Storrs (fig. 11) (Montana Inspector of Mines, 1904).

During this period of development, prospecting was concentrated on the Paddy Miles and the Storrs No. 3 beds. These beds were thicker and had larger coal reserves above the valley floor than did the Cokedale bed. The Washoe Coal Co. Nos. 1, 2, 3, and 4 mines were developed (pl. 1). The largest mine was the Washoe Coal Co. No. 3 on the Storrs No. 3 bed (Calvert, 1912a, p. 394).

The Washoe Coal Co. No. 4 mine was a horizontal drift driven 860 feet northward on the Big Dirty Bed in the NE¼ sec. 35, T. 2 S., R. 7 E. (pl. 5). The bed ranged in width from 10 to 25 feet, but none of the coal was of commercial value.

The Washoe Coal Co. mines were situated in much the same way as the Meadow Creek mines—along the strike of coal beds in a tightly folded syncline. The coal was generally crushed or broken and admixed with clastic partings, many of which could not be separated from the coal either in the mining or by washing. Sufficient tonnage of clean coking coal to supply the company's elaborate facilities was never found, and in 1907, after spending nearly $1 million, the Washoe Coal Co. closed its operations at Storrs (Parsons, 1907, p. 1074). Most of the 100 coke ovens were never fired.

In 1905, production by the Washoe Coal Co. was 500 tons, and 16 men were employed. In 1906 there was no recorded production (Montana Inspector of Mines, 1906). In 1907, the production by 98 men was 14,978 tons, of which 14,074 tons was made into coke (Rowe, 1908b, p. 718).

In 1915 the Maxey Bros. took over the Washoe Coal Co. property at Storrs. Under the name of Chestnut Hill Coal Co., they mined some coal for the domestic trade in Bozeman.

Late in 1921 W. D. Gibson consolidated the more promising leases, including the Meadow Creek mines, Washoe Coal Co. mines, and the Maxey Bros. developments, in secs. 23, 26–28, 34, and 35, T. 2 S., R. 7 E. (pl. 5), to form the Meadow Creek Coal Co. This company did not reopen the Washoe Coal Co. mines.

The Cokedale bed was sampled in the Washoe Coal Co. No. 3 mine (locs. 40, 41, pl. 1). The bed's stratigraphic relations and correlation are shown on plate 4. Analyses of samples from the Cokedale and Paddy Miles beds are given in table 2. Analyses of coal from the Storrs No. 3 bed are given in table 3, coking tests of this coal are given in table 4, and analyses of the coke from this coal are given in table 5.

PAYNE MINE

This small mine, opened by Oscar Payne in about 1938 in the SW¼ sec. 35, T. 2 S., R. 7 E. (pl. 1), was a horizontal drift on the Storrs No. 3 bed. The small amount of coal produced was for domestic use.

MONROE MINE

The Monroe mine, developed in the early 1900's by William Monroe in the NW¼ sec. 2, T. 3 S., R. 7 E. (pl. 1), was a horizontal drift on the Maxey bed. A small amount of coal was mined for domestic use. Calvert (1912a, p. 396) briefly described the coal bed after visiting this mine in 1908.

The stratigraphic relations and correlation of the Maxey bed in the Monroe mine, locality 77 (pl. 1), are shown on plate 4.

PLANISHEK MINE

The Planishek mine, developed in the early 1930's by Joe Planishek and his sons in the NE¼ sec. 2, T. 3 S., R. 7 E. (pl. 1), was a horizontal drift that extended about 250 feet on the strike of the Maxey bed. The production was small and for domestic use; the mine was closed in 1933.

HARRISON MINE

This small mine, in the NE¼ sec. 2, T. 3 S., R. 7 E. (pl. 1), was developed by Henry Harrison in the early 1900's. The entry was a horizontal drift on the Maxey bed and extended 700 feet north of the portal. Calvert (1912a, p. 396–397) visited this mine in 1908 and briefly described it.

The coal is fairly clean and hard, irregular in thickness, and usually slickensided. The bed's location in a tightly folded syncline (pl. 1) considerably influenced the character of the coal.

Production was chiefly during the winter months and for a small domestic trade. During 1908 four men mined 462 tons of coal; during 1909 three men mined 491 tons (Montana Inspector of Mines, 1909, 1910). The mine was closed in 1910.

The stratigraphic relations and correlation of the Maxey bed in the Harrison mine, locality 78 (pl. 1), are shown on plate 4.

MORAN MINE

The Moran mine, a horizontal drift on the Big Dirty bed in the NE¼ sec. 2, T. 3 S., R. 7 E. (pl. 1), was developed in the early 1930's by Ernest Moran. Production was small and limited to domestic use.

TRAIL CREEK DISTRICT

The Trail Creek district was developed later than other districts of the Livingston coal field, primarily because of the difficulty in transporting coal to shippers at Brisbin and Chestnut. The Yellowstone Park Railway—an 11-mile private road completed in about 1899 by the Turner Bros. and leased to the Northern Pacific Railway Co.—began at Mountain Siding (near Chestnut) and ended at the Maxey Bros. mines. The railroad was first built to Hoffman; later it was extended to Chimney Rock. After the first closing of the Maxey Bros. mines in 1917, the tracks were removed.

The Mountain House and the Maxey Bros. mines became large producers in the Trail Creek district. As these mines grew, the communities of Hoffman and Chimney Rock—near the Mountain House and Maxey Bros. mines respectively—grew apace (pl. 1).

MOUNTAIN HOUSE MINE

In 1878 W. H. Randall and N. M. Black began development of the Mountain House mine, near the top of the divide between Trail and Meadow Creeks, in the NW¼SE¼ sec. 18, T. 3 S., R. 8 E. (pl. 1). It was named for Mountain House, a stage stop half a mile southeast of the mine on the road from Bozeman to Yellowstone Park.

In 1883 W. F. Sloan, E. D. Ferguson, and W. McIntyre bought Randall's interest in the mine. A horizontal drift extended 175 feet from the entry by the end of 1883, and during the next 2 years, 1,200 feet of workings was developed. Production in 1885 was 609 tons (U.S. Geol. Survey, 1885, p. 38).

C. W. Hoffman acquired the mine about 1896 after closing his operations at Timberline. He renamed the mine after himself but operated as the Mountain House Coal Co. In 1897 the No. 1 slope (pl. 6), which was an inclined shaft oblique to the 45° dip, was started on the lower split of the Storrs No. 3 bed (pl. 4). This slope

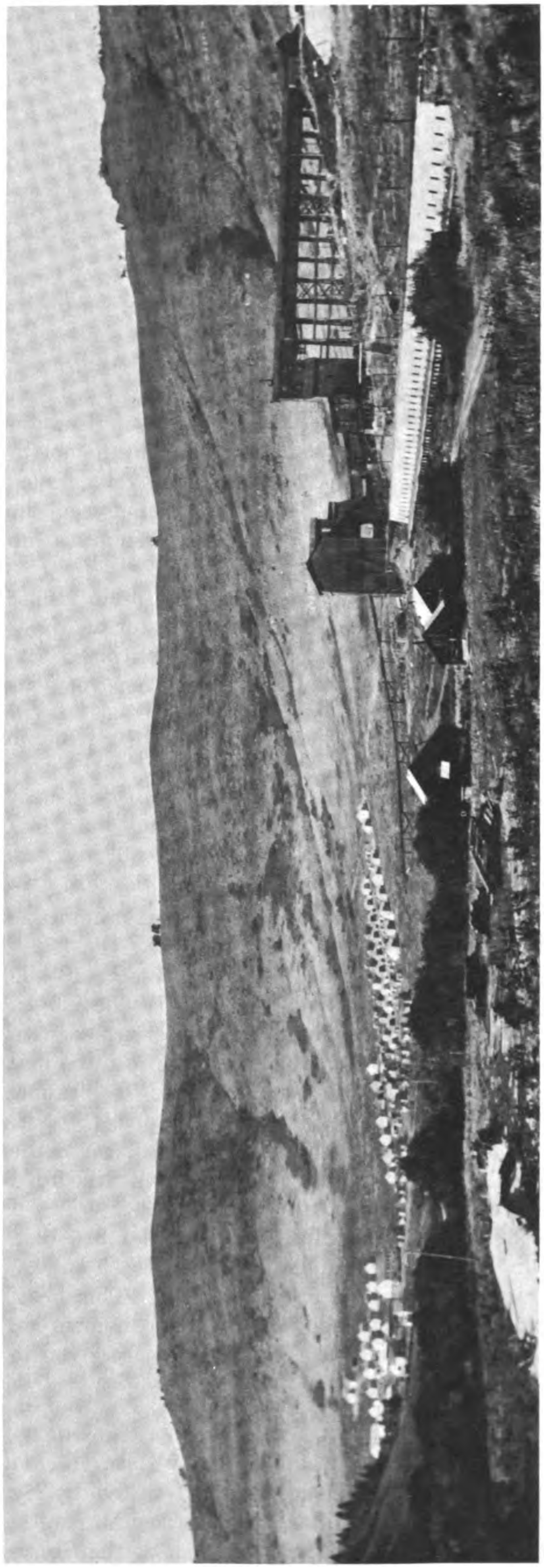


FIGURE 11.—The tipple, washing plant, and coke ovens of the Washoe Coal Co. in the Livingston coal field. Community of Storrs is in background. The view is north; Washoe Coal Co. mines were to the right of the area shown. Photographed by W. R. Calvert in 1908.

was extended down 200 feet, and the coal was removed from entries to the right (Montana Inspector of Mines, 1900). On the northwest side of the slope, the workings eventually extended to 2,700 feet (pl. 6); on the southeast side, to 530 feet.

J. W. Anderson and T. J. Evans leased the Mountain House Coal Co. property in 1905 and began development of the No. 2 slope. This inclined shaft was driven on the 45° dip of the Storrs No. 3 coal bed. By 1908 the No. 2 slope had been driven 320 feet; the workings extended 1,675 feet northwest and 1,495 feet southeast from the bottom of the slope (pl. 6). In the southeastern workings the Storrs No. 3 bed and the lower, unnamed bed were mined for nearly 1,200 feet—almost to the surface or to the contact with the older Hoffman workings above. In 1907 a fire broke out in the northwestern workings and the entries had to be sealed about 700 feet from the No. 2 slope. Between the sealed entries and the slope, both beds were mined up to the older Hoffman workings.

Although production data for the Mountain House mine are incomplete, the Montana Inspector of Mines (1900, 1906, 1909, 1910) reported a daily output of 125 tons by 1900, and reported data for other years as follows:

Year	*Tons of coal produced*	*Men employed*
1905	2, 610	19
1906	12, 022	30
1907	18, 908	34
1908	21, 639	45
1909	18, 906	50
1910	25, 452	54

The coal was shipped throughout the State for domestic use. The mine was closed in 1912.

The Sheep Corral mine, in the NW¼ sec. 18, T. 3 S., R. 8 E. (pl. 1), was a horizontal drift developed by the Mountain House Coal Co. that connected with the main workings of the Mountain House mine and extended those workings to the northwest. The tunnel was on the Storrs No. 3 bed, which dipped 41° NE. at the portal, and it extended at least 1,000 feet to the northwest. Production for this mine was recorded with that of the Mountain House mine.

The coal beds were sampled at localities 81–86 in the Mountain House mine and at localities 79 and 80 (pl. 1) in the Sheep Corral workings. The beds' stratigraphic relations and correlation are shown on plate 4, and the analyses of five samples are given in table 2.

STEVENSON MINE

The Stevenson mine, in the SW¼SW¼ sec. 17, T. 3 S., R. 8 E. (pl. 1) was reportedly started by Sy Mounts in 1884. The mine began as a horizontal drift driven southward along the strike of the Storrs No. 3 coal bed and continued as a slope driven northeastward 150 feet. Mounts' work was limited to development; no production was reported. The mine was closed in 1889 owning to difficulty in transporting the coal to the railroad and to the low price of coal at that time.

The tunnel was reopened by A. Stevenson in 1907, and the workings were extended 600 feet southeastward (pl. 7). Production was small and was sold in Bozeman for domestic use. The mine was closed in 1909.

In 1934 J. W. Anderson reopened the mine by driving a crosscut rock tunnel and a slope (pl. 7). Again, production was small; it was trucked to Bozeman for domestic use. The mine was abandoned in 1940.

KOUNTZ MINE

J. J. Kountz and George Cox, who operated as the Park County Coal Co., developed the Kountz mine, in the NW¼ sec. 20, T. 3 S., R. 8 E. (pl. 1), during the late 1890's by driving an inclined shaft on the lower split of the Storrs No. 3 bed. By 1907 the incline was 600 feet deep and followed the coal, which dipped 42° NE. The coal was mined to a depth of 200 feet. About 1907 J. W. Anderson and T. J. Evans acquired the mine. During their operation the incline was advanced to a depth of 700 feet, and the workings, which were terminated at faults, were extended 750 feet northwestward and 550 feet southeastward. The mine was closed in 1910 because of fire (Calvert, 1912a, p. 399).

Coal production was 3,000 tons in 1905 and 5,580 tons in 1906; it was shipped to Bozeman and other nearby towns for domestic trade (Montana Inspector of Mines, 1906). During those years the mine employed 10–15 men. In 1907, mining by 45 men yielded 8,366 tons, and in 1908, mining by 35 men yielded 5,728 tons (Montana Inspector of Mines, 1909). Production during 1909 was recorded with that of the Mountain House mine, which was operated by Anderson and Evans.

The lower split of the Storrs No. 3 bed was sampled at locality 87 (pl. 1) at the Kountz mine. The split's stratigraphic relations and correlation are shown on plate 4, and the analysis of a sample (No. 87) is given in table 2.

GASAWAY MINE

In 1908 D. E. Gasaway drove a 300-foot rock tunnel from Trail Creek northeast to intersect four coal beds (pl. 2) in the NW¼SE¼ sec. 20, T. 3 S., R. 8 E. (pl. 1). The coal beds dip 64° SW. and have been badly broken by faulting. A small amount of coal was produced for domestic use.

FEATHERSTONE MINE

B. Featherstone opened this small mine, in the SW¼SE¼ sec. 21, T. 3 S., R. 8 E. (pl. 1), in the early

1900's by means of a 55-foot-long shaft inclined northeastward on the Big Dirty bed. The coal at the surface is overturned and dips 45° NE., but, at the bottom of the slope, the dip reversed to 60° SW. Many small faults were discovered in the mine, and the coal was soft. A short horizontal drift was driven southeastward, but it intersected a fault and was abandoned. The mine was operated for about 1 year, and a small amount of coal was produced for domestic use.

HEDGES BROS. MINE

In 1884 the Hedges brothers drove a horizontal drift into the Maxey bed in the NW¼NW¼ sec. 28, T. 3 S., R. 8 E. (pl. 1). A small amount of coal was produced for the Anaconda Copper Co. smelters at Butte. Operations of the Hedges Bros. and the Byam Bros. mines were merged by G. V. Moroford in 1885. The Hedges Bros. mine was closed at the end of 1885.

BYAM BROS. MINE

By 1884 H. C. and O. O. Byam—sons of the famed judge, Dr. D. L. Byam of the Vigilante Miners Court in Virginia City, Mont.—had developed a 170-foot-long horizontal drift on the Maxey bed in the NE¼NW¼ sec. 28, T. 3 S., R. 8 E. (pl. 1). G. V. Moroford merged operations of the Byam Bros. and the Hedges Bros. mines in 1885 following the death of O. O. Byam by an accident in the Byam Bros. mine. The combined operations were suspended after only 1 year. From 1887 to 1892 H. C. Byam worked the mine intermittently. In 1889 about 20 tons per day was produced for use by the Dodson lime kiln, a few miles south of Livingston. Production for 1890 was approximately 1,000 tons.

MAXEY BROS. NOS. 1, 2, AND 3 MINES

Daniel Maxey in 1889 drove an inclined shaft to a depth of 40 feet on the Maxey bed in the SE¼NE¼ sec. 28, T. 3 S., R. 8 E., just west of Trail Creek, near what later became the community of Chimney Rock (pl. 1). Development was intermittent, and about 1895 A. B. Cook acquired the property and operated as the Trail Creek Coal Co. (Montana Inspector of Mines, 1900). A 260-foot slope was driven southwestward from the No. 1 tunnel and entries are northwestward and southeastward. The dip of the coal increased from 34° to nearly vertical (Calvert, 1912a, p. 399), several faults were struck, and the mine was abandoned. Daniel Maxey reacquired the mine in 1903 and with his sons, John, William, David, and George, operated as the Maxey Coal Co. The company developed the largest producing mine in the Trail Creek district. The mine was best known as the Maxey Bros. coal mine (fig. 12), although it has been referred to as the Byam, Cook, Maxey, and the Chimney Rock mines.

FIGURE 12.—The Maxey Bros. No. 1 mine portal and tipple, Livingston coal field. Wooded hills in background are underlain by Eocene conglomerate and volcanic breccia. Chimney Rock shows on skyline on right side of photograph. View is to the west. Photographed by W. R. Calvert in 1908.

In 1903 the Maxey Bros. reopened the mine, drove southward through the fault, and resumed production (Calvert, 1912a, p. 399). When they found that the dip of the coal bed lessened southward, they made a new entry, Maxey Bros. No. 2 mine (pl. 6), and all the coal mined during 1908–10 came from these workings. In 1910 a third entry, Maxey Bros. No. 3 mine (pl. 6), was developed as the main haulageway and connected with the workings of the No. 2 mine. Midway between these workings, driven from the No. 2 water-level tunnel, was a 1,100-foot incline that trended 45° SW. (pl. 6). This incline was driven on the dip of the coal. Near the hoist the dip was 18° SW.; 600 feet farther down the incline the dip had gradually flattened to 14° NW.; and at the bounding fault that terminated the mine to the west (pl. 6), the dip had flattened to 10° NW.

The main workings of the Maxey Bros. mines lie between two northwest-trending faults; the north fault offset the coal 100 feet; the south fault, more than 150 feet (pl. 1). After the main slope reached the south fault, a crosscut was made that passed through the fault and into the stratigraphically higher beds of the Eagle Sandstone. During this exploration a small coal bed was opened—probably the Bottamy bed—about 150 feet stratigraphically above the Maxey bed. No further exploration was made along this fault, and by about 1915 the blocked-out reserves had all been mined.

The Maxey bed was unusually thick in this part of the Livingston coal field. The bed in the Maxey Bros. mines was 9 feet thick; it had a sandstone roof, a shale floor, and a prominent 2- to 4-inch sandstone parting 66 inches from the base (pl. 4). This parting was left as a roof during the early mining; but later, when the pillars were mined, the coal above the parting was removed.

The Maxey Bros. mined less than 500 tons in 1906. In 1907, however, they mined 7,629 tons, employing 53 men; in 1908, 15,520 tons, employing 52 men; in 1909, 15,564 tons, employing 28 men; and in 1910, 32,308 tons, employing 47 men (Montana Inspector of Mines, 1909, 1910). Production in 1911 was 31,402 tons. Mining continued through 1914, but production figures are not available.

During 1915–18 the mine was virtually idle while the operators attempted unsuccessfully to locate the Maxey bed in secs. 27 and 34, T. 3 S., R. 8 E., and sec. 3, T. 4 S., R. 8 E. The pillars were mined during 1930–31 and generally produced 50–60 tons per day; at times they yielded as much as 100 tons of coal. The mine was abandoned in 1931.

Approximately 200,000 tons of coal was produced from 22 acres of underground workings while the mines were in operation. The coal was an excellent fuel for domestic purposes because it left no clinkers, and most of the output was shipped to many parts of the State.

The stratigraphic relations and correlation of the Maxey bed in the Maxey Bros. No. 2 mine, locality 88 (pl. 1), and of the Middle bed at the Maxey Bros. prospect, locality 89 (pl. 1), are shown on plate 4, and the analyses of a sample from each locality are given in table 2.

KEARNS PROSPECT

In the late 1890's W. M. Kearns sank a prospect shaft on a steeply dipping unnamed bed (this bed may correlate with a part of the Big Dirty bed) in the NE¼ sec. 34, T. 3 S., R. 8 E. (pl. 1). The coal bed was too thin and impure to be of commercial value, and development stopped in about 1900.

BOTTAMY NOS. 1 AND 2 MINES

Many prospects were made along the north slope of Pine Creek valley in secs. 3 and 4, T. 4 S., R. 8 E. The Avant Courier (Feb. 19, 1885) briefly referred to the Pine Creek mines—owned by Wilber and Co.—which were developed by about 600 feet of tunnels. H. Kohler, J. W. Ponsford, L. Swan, F. D. Pease, and C. Daly also prospected in this area during the 1880's and 1890's. The greatest mining efforts in the Pine Creek area were those of H. Bottamy during 1907–34, and those of his son, G. H. Bottamy, during 1914–57.

The Bottamy prospect, in the SW¼NE¼ sec. 4, T. 4 S., R. 8 E. (pl. 1), was a slope driven in 1907 by H. Bottamy, 150 feet northeastward on the Bottamy bed, which dipped 15° NE. at this location. Section 95 (pl. 4) of the coal bed was measured 50 feet from the portal. The prospect was abandoned in 1909.

The Bottamy No. 1 mine, in the NE¼NW¼ sec. 4, T. 4 S., R. 8 E. (pl. 1), was started in 1909 by H. Bottamy with a horizontal drift on the Bottamy bed. By 1934, when the mine was abandoned, the workings had three horizontal drifts driven northwestward, each about 250 feet long. Coal section 94 (pl. 4) was measured near the main portal.

The Bottamy No. 2 mine, in the NE¼NW¼ sec. 4, T. 4 S., R. 8 E., was opened by G. H. Bottamy in 1936 (pl. 1). The mine operated as the Pine Creek Coal Co. and was developed from two horizontal drifts driven about 300 feet northwestward on the strike of the Bottamy bed (No. 93, pl. 4). The mine was worked intermittently through 1957 and was the last one active in the Livingston coal field.

Production from these mines was small owing to the difficulty in transporting the coal to rail facilities. The output was hauled to Livingston for domestic use.

The stratigraphic relations and correlation of the Bottamy bed in the Bottamy Nos. 1 and 2 mines, localities 94 and 93 (pl. 1), and at the Bottamy prospect, locality 95 (pl. 1), are shown on plate 4.

BRIDGER CANYON DISTRICT

In the Bridger Canyon district, two coal beds were prospected. The relation of these beds to those in the nearby Meadow Creek district is unknown; however, they are in the lower coal zone and are perhaps equivalent to the Big Dirty and Maxey beds. The 4-foot-thick lower bed and the 6-foot-thick upper bed are separated by 25 feet of massive sandstone. Both beds contain many partings of shale, bone, and impure coal. No mines were developed on these beds.

In the SE¼ sec. 34 is an abandoned stone quarry (pl. 1) where sandstone was once quarried for building stone used largely in Bozeman. During the operation of this quarry, both coal beds were exposed for a distance of 200 feet and to a depth of nearly 50 feet. Neither the thickness nor the quality of these beds warranted further development.

Two prospect tunnels—one, 200 feet long—were driven in sec. 26, T. 1 S., R. 6 E. The coal beds had the same characteristics as those described from secs. 34 and 35 and may be the same beds.

METHODS OF MINING

Structural and topographic conditions as well as the character of each coal bed influenced the methods of mining in the Livingston coal field. Three large anticlines and related structural features (pl. 1) affect the dip and strike of the coal. The coal beds are generally broken by many small faults where the coal-bearing rocks curve around the plunge of these folds. Faults of large displacement generally occur along the flanks of the major folds. In many places near the large faults, the coal beds are crumpled and shattered, and the offset of the beds is too great to permit economical mining operations.

The poor structural location of most mines in the Livingston coal field has been a major cause of the past mine failures and the resultant poor reputation of the field. Most mine entries were located in ravines for easy access to the coal and were generally developed on a slight grade along the strike of the coal bed for easy drainage and hauling. Most headings were double timbered and lagged. As mining progressed along the strike in the first level, inclined shafts were developed for expansion at depth. Mining was by the room-and-pillar or the chute-and-pillar method. Rooms or chutes were developed at right angles to the haulageways. The rooms were worked on the longwall plan, as there were no pillars between them. (See pl. 8.) Under some conditions, generally as the dip of the bed increased, the chutes were driven across the dip at an angle, so that the grade on which coal was moved to the haulageway was not as great. The width of the room chutes varied in proportion to the dip of the coal. In the larger operations the chutes were propped on both sides, and the space between the chutes was filled with coal. Generally the dip of the coal bed was steep enough that explosives were not required, and the coal was undercut and allowed to slide down into the chute. Coal was loaded into cars by gravity from the chutes, and the loaded cars were pulled up the inclined shafts to the tipple by steam-driven winches.

All the coal beds of the Livingston coal field have one or more partings; hence, all the coal requires washing in order to yield a product having an acceptably low ash content. The partings, which are heavier than the coal, usually can be removed in a washing plant. Generally the coal was screened before shipment. At Cokedale the finer size material generally went to the coke ovens, and the larger size material was shipped for industrial use; however, when the market for this commercial size declined, the larger size material was crushed at the washing plant and sent to the coke ovens.

The size distribution of a mine-run sample of the Middle bed from the Cokedale No. 3 mine was described by Smith [2] as follows: Larger than 1½ inches, 2.04 percent; 1½–¾ inches, 6.67 percent; ¾–⅜ inch, 16.82 percent; ⅜–³⁄₁₆ inch, 21.35 percent; ³⁄₁₆ inch–20 mesh per inch, 39.92 percent; and smaller than 20 mesh per inch, 13.20 percent.

[2] Smith, G. R., 1954, Carbonization of Montana coal: Bozeman, Montana State College unpub. M.S. thesis, p. 40.

Mining methods in the Livingston coal field were also influenced by the need for good ventilation. The Rocky Canyon mine and the Timberline No. 3 mine contained explosive gases (Montana Inspector of Mines, 1896, p. 43). The Mountain Side mine was fairly well ventilated, but some lower workings contained gas (Rowe, 1908b, p. 675). Gas was also reported to be in the Mountain House mine (Montana Inspector of Mines, 1906, p. 78).

COAL RESERVES

The estimated coal reserves in the Eagle Sandstone in the Livingston coal field as of January 1, 1965, totaled more than 300 million short tons. These reserves are in beds that are 14 inches or more thick and are within 3,000 feet of the surface. The distribution of reserves in individual coal beds and townships and by categories according to thickness of the bed, amount of overburden, and classes (measured and indicated, and inferred reserves) is shown in table 8.

The coal-reserve estimates given in this report for the Livingston coal field were calculated for individual beds by use of 7½-minute quadrangles enlarged to a scale of 1:15,840 as aerial units. On the map of each bed, the outcrop of the coal, location of all measured sections, and subsurface information were compiled. The boundaries between overburden thicknesses, coal-thickness categories, and reserve classes (measured, indicated, and inferred) were plotted on the maps of the beds in accordance with standard procedures of the U.S. Geological Survey (Averitt, 1961).

The weight of bituminous coal in the ground is most affected by the coal's ash content and, to a lesser extent, by its content of fixed carbon, moisture, and volatile matter. Precise data on the weight of coal in the Livingston coal field were not available, and the average of 1,800 tons per acre-foot (Averitt, 1961, p. 18) was used in all calculations of reserves.

Partings more than three-eighths inch thick were omitted in determining the thickness of an individual bed. Beds or parts of beds made up of alternating layers of thin coal and partings were excluded if the partings made up more than half the total thickness.

Only a small amount of coal in the Livingston coal field could be classed as measured, inasmuch as the points of observation for measured coal should be no greater than half a mile apart and at least three in number. Large amounts of coal could be classed as indicated, because many of the points of observation were within the interval of 1½ miles, and projection of visible data on geologic evidence was reasonable for this distance. In reporting reserves for the Livingston coal field, therefore, these two classes are combined as "measured and indicated." The reserve table shows that approximately 85 percent of the total estimated reserves is included in this class. Inferred reserves are quantitative estimates, primarily based on knowledge of the geologic character of the coal beds and on the assumption that the continuity of the beds extends as much as 2 miles from the nearest observation point. Areas mined out or destroyed in mining were measured and subtracted from the original reserves because of the paucity of accurate production records.

The percentages of coal recovered and lost in mining vary in different beds and areas; they are related to thickness and quality of the coal, nature of the roof and floor, amount of overburden, mining methods employed, and other factors. The lack of complete production or mining records for the Livingston coal field precludes an accurate estimate of the percentage of coal recovered in mining. In a few of the larger mines more than 50 percent of the coal was recovered, and in most of the small mines recovery probably was less; however, in the larger mines for which records were available, the average recoverability seems to have been approximately 50 percent, which is similar to the nationwide average (Averitt, 1961, p. 25). Statistically, then, the recoverable reserves for the Livingston coal field would be half of the remaining reserves listed in table 8.

The future of the Livingston coal field is in the development of the coal in areas where large-scale mining could be economic. These areas include the coal at depth in the Cokedale and Timberline districts, the Eldridge Creek synclinal area between these two

TABLE 8.—*Estimated coal reserves in the Eagle Sandstone, Livingston coal field, Montana, January 1, 1965*

[In thousands of short tons]

Coal bed	Overburden (ft)	Measured and indicated				Inferred				Total all categories			Grand total
		14–28 in.	28–42 in.	>42 in.	Total	14–28 in.	28–42 in.	>42 in.	Total	14–28 in.	28–42 in.	>42 in.	
T. 2 S., R. 7 E.													
Cokedale	0–1,000		1,459	7,016	8,475		795		795		2,254	7,016	9,270
	1,000–2,000		1,417	9,930	11,347		933		933		2,350	9,930	12,280
	2,000–3,000		1,115	8,686	9,801		1,106		1,106		2,221	8,686	10,907
	Total		3,991	25,632	29,623		2,834		2,834		6,825	25,632	32,457
Paddy Miles	0–1,000	763	1,766	4,663	7,192		1,313		1,313	763	3,079	4,663	8,505
	1,000–2,000	899	2,029	3,286	6,214		1,382		1,382	899	3,411	3,286	7,596
	2,000–3,000		3,321	2,494	5,815		1,624		1,624		4,945	2,494	7,439
	Total	1,662	7,116	10,443	19,221		4,319		4,319	1,662	11,435	10,443	23,540
Storrs No. 3	0–1,000		69	8,893	8,962	760			760	760	69	8,893	9,722
	1,000–2,000			7,476	7,476	829			829	829		7,476	8,305
	2,000–3,000			6,705	6,705	991			991	991		6,705	7,696
	Total		69	23,074	23,143	2,580			2,580	2,580	69	23,074	25,723
Unnamed bed at base of upper coal zone	0–1,000	847	355		1,202					847	355		1,202
	1,000–2,000	786	258		1,044					786	258		1,044
	2,000–3,000	772	161		933					772	161		933
	Total	2,405	774		3,179					2,405	774		3,179
Total, 4 beds		4,067	11,950	59,149	75,166	2,580	7,153		9,733	6,647	19,103	59,149	84,899
T. 2 S., R. 8 E.													
Cokedale	0–1,000	138	553	9,009	9,700		2,212		2,212	138	2,765	9,009	11,912
	1,000–2,000		311	10,243	10,554		2,281		2,281		2,592	10,243	12,835
	2,000–3,000			11,146	11,146		2,316		2,316		2,316	11,146	13,462
	Total	138	864	30,398	31,400		6,809		6,809	138	7,673	30,398	38,209
Paddy Miles	0–1,000		3,316	3,456	6,772			2,580	2,580		3,316	6,036	9,352
	1,000–2,000	8	3,137	2,915	6,060			2,765	2,765	8	3,137	5,680	8,825
	2,000–3,000	71	3,587	2,984	6,642			2,949	2,949	71	3,587	5,933	9,591
	Total	79	10,040	9,355	19,474			8,294	8,294	79	10,040	17,649	27,768
Storrs No. 3	0–1,000		968	46	1,014	1,797			1,797	1,797	968	46	2,811
	1,000–2,000		795	138	933	1,313			1,313	1,313	795	138	2,246
	2,000–3,000		864	438	1,302	1,290			1,290	1,290	864	438	2,592
	Total		2,627	622	3,249	4,400			4,400	4,400	2,627	622	7,649
Middle	0–1,000	46	4,285		4,331	968	760		1,728	1,014	5,045		6,059
	1,000–2,000		4,044		4,044	691	760		1,451	691	4,804		5,495
	2,000–3,000		4,562		4,562	760	864		1,624	760	5,426		6,186
	Total	46	12,891		12,937	2,419	2,384		4,803	2,465	15,275		17,740
Total, 4 beds		263	26,422	40,375	67,060	6,819	9,193	8,294	24,306	7,082	35,615	48,669	91,366

TABLE 8.—*Estimated coal reserves in the Eagle Sandstone, Livingston coal field, Montana, January 1, 1965*—Continued

Coal bed	Overburden (ft)	Measured and indicated				Inferred				Total all categories			Grand total
		14–28 in.	28–42 in.	>42 in.	Total	14–28 in.	28–42 in.	>42 in.	Total	14–28 in.	28–42 in.	>42 in.	
T. 2 S., R. 9 E.													
Middle	0–1,000			9,562	9,562		4,147		4,147		4,147	9,562	13,709
	1,000–2,000			8,640	8,640		4,458		4,458		4,458	8,640	13,098
	2,000–3,000			7,718	7,718		5,288		5,288		5,288	7,718	13,006
	Total			25,920	25,920		13,893		13,893		13,893	25,920	39,813
Total				25,920	25,920		13,893		13,893		13,893	25,920	39,813
T. 3 S., R. 7 E.													
Storrs No. 3	0–1,000	35		46	81					35		46	81
	1,000–2,000												
	2,000–3,000												
	Total	35		46	81					35		46	81
Total		35		46	81					35		46	81
T. 3 S., R. 8 E.													
Paddy Miles	0–1,000			922	922							922	922
	1,000–2,000												
	2,000–3,000												
	Total			972	922							922	922
Storrs No. 3	0–1,000	138	242	852	1,232					138	242	852	1,232
	1,000–2,000												
	2,000–3,000												
	Total	138	242	852	1,232					138	242	852	1,232
Unnamed bed (or lower split of the Storrs No. 3)	0–1,000	23	35	4,044	4,102					23	35	4,044	4,102
	1,000–2,000												
	2,000–3,000												
	Total	23	35	4,044	4,102					23	35	4,044	4,102
Middle	0–1,000			15,552	15,552			58	58			15,610	15,610
	1,000–2,000			5,760	5,760							5,760	5,760
	2,000–3,000												
	Total			21,312	21,312			58	58			21,370	21,370
Bottamy	0–1,000		14	9,298	9,312						14	9,298	9,312
	1,000–2,000			597	597							597	597
	2,000–3,000												
	Total		14	9,895	9,909						14	9,895	9,909
Maxey	0–1,000			24,618	24,618			2,822	2,822			27,440	27,440
	1,000–2,000			3,629	3,629							3,629	3,629
	2,000–3,000												
	Total			28,247	28,247			2,822	2,822			31,069	31,069
Total, 6 beds		161	291	65,272	65,724			2,880	2,880	161	291	68,152	68,604
T. 4 S., R. 8 E.													
Bottamy	0–1,000		94	3,602	3,696						94	3,602	3,696
	1,000–2,000												
	2,000–3,000												
	Total		94	3,602	3,696						94	3,602	3,696
Maxey	0–1,000			7,344	7,344			4,884	4,884			12,228	12,228
	1,000–2,000			98	98							98	98
	2,000–3,000												
	Total			7,442	7,442			4,884	4,884			12,326	12,326
Total, 2 beds			94	11,044	11,138			4,884	4,884		94	15,928	16,022
Grand total		4,526	38,757	201,806	245,089	9,399	30,239	16,058	55,696	13,925	68,996	217,864	300,785

districts, the Meadow Creek synclinal area in the Meadow Creek district, and the Pine Creek synclinal area in the Trail Creek district (pl. 1). Development of any of these areas should be preceded by a systematic drilling program to determine whether the coal beds are thick enough and whether the quality of the coal is high enough to justify the expense of opening a mine. The high cost of mining the relatively thin and structurally complicated coals in the Livingston coal field may be offset by future demands—such as the needs of the expanding chemical industry—for these higher rank coals. Future mining in this field could be successful only if the mine operations are planned for the specific geological conditions.

REFERENCES

American Society for Testing Materials, 1955, Standard specifications for classification of coals by rank, *in* 1955 Book of ASTM Standards, pt. 5: Philadelphia, p. 1022–1026.

Averitt, Paul, 1961, Coal reserves of the United States—a progress report, January 1, 1960: U.S. Geol. Survey Bull. 1136, 116 p.

Belden, A. W., Delamater, G. R., and Groves, J. W., 1909, Washing and coking tests of coal: U.S. Geol. Survey Bull. 368, 53 p.

Calvert, W. R., 1912a, The Livingston and Trail Creek coal fields, Park, Gallatin and Sweetgrass Counties, Montana: U.S. Geol. Survey Bull. 471, pt. 2, p. 384–405.

———1912b, The Electric coal field, Park County, Montana: U.S. Geol. Survey Bull. 471, pt. 2, p. 406–422.

———1916, Geology of the Upper Stillwater Basin, Stillwater and Carbon Counties, Montana, with special reference to coal and oil: U.S. Geol. Survey Bull. 641–G, pt. 2, p. 199–214.

Cobban, W. A., 1958, Late Cretaceous fossil zones of the Powder River Basin, Wyoming and Montana, *in* Wyoming Geol. Assoc. Guidebook 13th Ann. Field Conf., 1958: p. 114–119.

———1962a, New baculites from the Bearpaw shale and equivalent rocks of the Western Interior: Jour. Paleontology, v. 36, no. 1, p. 126–135.

———1962b, Baculites from the lower part of the Pierre Shale and equivalent rocks in the Western Interior: Jour. Paleontology, v. 36, no. 4, p. 704–718.

Cobban, W. A., Erdmann, C. E., Lemke, R. W., and Maughan, E. K., 1959, Revision of Colorado group on Sweetgrass arch, Montana: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 12, p. 2786–2796.

Combo, J. X., Brown, D. M., Pulver, H. F., and Taylor, D. A., 1949, Coal resources of Montana: U.S. Geol. Survey Circ. 53, 28 p.

Daly, R. L., 1910, Geology of the North American Cordillera at the forty-ninth parallel: Canada Dept. Interior, Rept. Chief Astronomer, v. 2 and 3, p. 1–799.

Davis, W. M., 1886, Relation of the coal of Montana to the older rocks, *in* Report on the mining industries of the United States, 1880: U.S. Census, 10th, v. 15, p. 697–737.

Eicher, D. L., 1960, Stratigraphy and micropaleontology of the Thermopolis Shale [Wyoming]: Yale Univ. Peabody Mus. Nat. History Bull. 15, 126 p.

Eldridge, G. H., 1886, Montana coal fields, *in* Report on the mining industries of the United States, 1880: U.S. Census, 10th, v. 15, p. 739–757, 781–789.

Fisher, C. A., 1908, Southern extension of the Kootenai and Montana coal-bearing formations in northern Montana: Econ. Geology, v. 3, no. 1, p. 77–99.

Gill, J. R., and Cobban, W. A., 1961, Stratigraphy of lower and middle parts of the Pierre shale, northern Great Plains, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D185–D191.

———1962, Red Bird Silty Member of the Pierre Shale, a new stratigraphic unit, *in* Short papers in geology, hydrology, and topography: U.S. Geol. Survey Prof. Paper 450–B, p. B21–B24.

Goddard, E. N., chm., and others, 1948, Rock-Color Chart: Washington, Natl. Research Council (repub. by Geol. Soc. America, 1951), 6 p.

Hackett, O. M., Visher, F. N., McMurtrey, R. G., and Steinhilber, W. L., 1960, Geology and ground water resources of the Gallatin Valley, Gallatin County, Montana: U.S. Geol. Survey Water-Supply Paper 1482, 282 p.

Hague, Arnold, 1899, Description of the Absaroka quadrangle [Crandall and Ishawooa quadrangles, Wyo.]: U.S. Geol. Survey Geol. Atlas, Folio 52, 6 p.

Hail, W. J., Jr., and Gill, J. R., 1953, Results of reconnaissance for uraniferous coal, lignite, and carbonaceous shale in western Montana: U.S. Geol. Survey Circ. 251, 9 p.

Hancock, E. T., 1918, Geology and oil and gas prospects of the Lake Basin field, Montana: U.S. Geol. Survey Bull. 691–D, p. 101–147.

Hayden, F. V., 1872, Preliminary report of the United States Geological Survey of Montana and portions of adjacent Territories, being a fifth annual report of progress: Washington, 538 p.

———1873, Sixth annual report of the United States Geological Survey of the Territories for the year 1872: Washington, 844 p.

Horberg, Leland, 1940, Geomorphic problems and glacial geology of the Yellowstone Valley, Park County, Montana: Jour. Geology, v. 48, no. 3, p. 275–303.

Horn, G. H., 1955, Geologic and structure map of Sussex and Meadow Creek oil fields and vicinity, Johnson and Natrona Counties, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–164.

Iddings, J. P., and Weed, W. H., 1894, Livingston atlas sheet [Montana]: U.S. Geol. Survey Geol. Atlas, Folio 1, 4 p.

Klepper, M. R., Weeks, R. A., and Ruppel, E. T., 1957, Geology of the southern Elkhorn Mountains, Jefferson and Broadwater Counties, Montana: U.S. Geol. Survey Prof. Paper 292, 82 p.

Knechtel, M. M., and Patterson, S. H., 1962, Bentonite deposits of the northern Black Hills district, Wyoming, Montana, and South Dakota: U.S. Geol. Survey Bull. 1082–M, p. 893–1030.

Knowlton, F. H., 1892, The fossil flora of the Bozeman coal field [abs.]: Biol. Soc. Washington Proc. 7, p. 153–154.

Lesquereux, Leo, 1873, Lignitic formation and fossil flora, *in* Hayden, F. V., Sixth annual report of the United States Geological Survey of the Territories for the year 1872: Washington, p. 317–427.

Lord, N. W., and others, 1913, Analyses of coals in the United States—[pt.] 1, Analyses [pt.] 2, Descriptions of samples: U.S. Bur. Mines Bull. 22, pt. 1, p.1–321; pt. 2, p. 322–1200.

Lyons, J. B., 1944, Igneous rocks of the northern Big Belt Range, Montana: Geol. Soc. America Bull., v. 55, no. 4, p. 445–472.

McDonald, Marguerita, and Burlingame, M. G., 1956, Montana's first commercial coal mine: Pacific Northwest Quart. v. 47, no. 1, p. 23–28.

McMannis, W. J., 1955, Geology of the Bridger Range, Montana: Geol. Soc. America Bull., v. 66, no. 11, p. 1385–1430.

Montana Inspector of Mines, 1890–1912, Annual report of the Inspector of Mines of the State of Montana [annual volumes for the years indicated].

Parsons, F. W., 1907, The operation of coal mines in Montana: Eng. Mining Jour., v. 84, pt. 2, no. 14, p. 1071–1074.

Pierce, W. G., 1963, Cathedral Cliffs Formation, the early acid breccia unit of northwestern Wyoming: Geol. Soc. America Bull., v. 74, no. 1, p. 9–21.

Pumpelly, Raphael, 1886, Bituminous coals and lignites of the Northwest, *in* Report on the mining industries of the United States, 1880: U.S. Census, 10th, v. 15, p. 691–695.

Reeside, J. B., Jr., 1927, The cephalopods of the Eagle sandstone and related formations in the western interior of the United States: U.S. Geol. Survey Prof. Paper 151, 87 p.

Richards, P. W., 1955, Geology of the Bighorn Canyon–Hardin area, Montana and Wyoming: U.S. Geol. Survey Bull. 1026, 93 p.

———1957, Geology of the area east and southeast of Livingston, Park County, Montana: U.S. Geol. Survey Bull. 1021–L, p. 385–438.

Roberts, A. E., 1957, Coal-bearing rocks and mines at Cokedale, Park County, Montana, *in* Billings Geol. Soc. Guidebook 8th Ann. Field Conf., Sept. 1957: p. 39–48.

———1963, The Livingston Group of south-central Montana *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–B, p. B86–B92.

———1964a, Geology of the Brisbin quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–256.

———1964b, Geology of the Chimney Rock quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–257.

———1964c, Geology of the Hoppers quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–258.

———1964d, Geology of the Livingston quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–259.

———1964e, Geologic map of the Maxey Ridge quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I–396.

———1964f, Geologic map of the Fort Ellis quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I–397.

———1964g, Geologic map of the Mystic Lake quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I–398.

———1964h, Geologic map of the Bozeman Pass quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I–399.

Robinson, C. S., Mapel, W. J., and Cobban, W. A., 1959, Pierre shale along western and northern flanks of Black Hills, Wyoming and Montana: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 1, p. 101–123.

Robinson, G. D., 1963, Geology of the Three Forks quadrangle, Montana: U.S. Geol. Survey Prof. Paper 370, 143 p.

Rowe, J. P., 1905, The Montana coal fields—their commercial value: Mining Mag., v. 11, p. 241–250.

———1906, Montana coal and lignite deposits: Montana Univ. Bull. 37, Geol. Ser. 2, 82 p.

Rowe, J. P., 1908a, Some economic geology of Montana: Montana Univ. Bull. 50, Geol. Ser. 3, 70 p.

——— 1908b, The coal and lignite deposits of Montana: Mining World, v. 28, p. 673–676, 717–718.

Schmidt, R. G., and Zubovic, Peter, 1961, Cobern Mountain overthrust, Lewis and Clark County, Montana, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–C, p. C175–C177.

Skeels, D. C., 1939, Structural geology of the Trail Creek-Canyon Mountain area, Montana: Jour. Geology, v. 47, no. 8, p. 816–840.

Spivey, R. S., 1940, Bentonite in southwestern South Dakota: South Dakota Geol. Survey Rept. Inv. 36, 56 p.

Stebinger, Eugene, 1914a, The coal fields of Montana: Am. Inst. Mining Eng. Trans. 46, p. 889–919.

———1914b, The Montana group of northwestern Montana: U.S. Geol. Survey Prof. Paper 90, p. 61–68.

Stone, R. W., 1909, Coal near the Crazy Mountains, Montana: U.S. Geol. Survey Bull. 341–A, p. 78–91.

Stone, R. W., and Calvert, W. R., 1910, Stratigraphic relations of the Livingston formation of Montana: Econ. Geology, v. 5; [pt.] 1, no. 6, p. 551–557; [pt.] 2, no. 7, p. 652–669; [pt.] 3, no. 8, p. 741–764.

Storrs, L. S., 1902, The Rocky Mountain coal field: U.S. Geol. Survey 22d Ann. Rept., pt. 3, p. 415–471.

U.S. Bureau of Mines, 1932, Analyses of Montana coals: U.S. Bur. Mines Tech. Paper 529, 129 p.

U.S. Department of the Interior, 1886, Directory of mines and metallurgical establishments east of 100th meridian, and of the mines of bituminous coal and lignite in the western States and Territories: U.S. Census, 10th, v. 15, p. 855–988.

U.S. Geological Survey, 1883–94, 1896, 1901–16, Mineral resources of the United States [annual volumes for the years indicated].

———1897, 1899, 1901, Annual reports [18th, 20th, and 21st].

U.S. Weather Bureau, 1948–57, Climatological data, Montana, *in* Climatological data for the United States by sections: U.S. Dept. Commerce, Ann. Summaries, v. 50–60.

Weed, W. H., 1891, The Cinnabar and Bozeman coal fields of Montana: Geol. Soc. America Bull., v. 2, p. 349–364.

———1892, The coal fields of Montana: Eng. Mining Jour., v. 53; [pt.] 1, no. 20, p. 520–522; [pt.] 2, no. 21, p. 542–543.

———1893, The Laramie and the overlying Livingston formation of Montana: U.S. Geol. Survey Bull. 105, p. 10–41.

———1899, Description of the Little Belt Mountains quadrangle [Montana]: U.S. Geol. Survey Geol. Atlas, Folio 56, 9 p.

Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments: Jour. Geology, v. 30, no. 5, p. 377–392.

Wood, H. E., 2d, and others, 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., v. 52, no. 1, p. 1–48.

Zapp, A. D., and Cobban, W. A., 1960, Some Late Cretaceous strand lines in northwestern Colorado and northeastern Utah, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400–B, p. B246–B249.

INDEX

[Italic page numbers indicate major references]

M

Mines—Continued

N

O

P

Q

R

S

T

U

V

W

Y

U. S. GOVERNMENT PRINTING OFFICE : 1966 O - 786-073

Stratigraphy of Madison Group Near Livingston Montana, and Discussion of Karst and Solution-Breccia Features

GEOLOGICAL SURVEY PROFESSIONAL PAPER 526-B

St

G

M

K

Fe

Stratigraphy of Madison Group Near Livingston Montana, and Discussion of Karst and Solution-Breccia Features

By ALBERT E. ROBERTS

GEOLOGY OF THE LIVINGSTON AREA, SOUTHWESTERN MONTANA

GEOLOGICAL SURVEY PROFESSIONAL PAPER 526-B

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1966

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 30 cents (paper cover)

CONTENTS

ILLUSTRATIONS

TABLE

STRATIGRAPHY OF MADISON GROUP NEAR LIVINGSTON, MONTANA, AND DISCUSSION OF KARST AND SOLUTION-BRECCIA FEATURES

By Albert E. Roberts

ABSTRACT

The Madison Group (Mississippian) near Livingston, southwestern Montana, is predominantly a marine-carbonate sequence in which limestone, dolomitic limestone, and dolomite alternate cyclically. The group is divided into two formations: the Lodgepole Limestone (in part Kinderhook age and in part Osage age) and the Mission Canyon Limestone (in part Osage age and in part Meramec age). The Lodgepole is subdivided into the Paine Shale and Woodhurst Limestone Members. The Mission Canyon is subdivided into two unnamed members; the upper member is equivalent to the Charles Formation of central and eastern Montana. Karst deposits and solution-breccia beds are both conspicuous features on or within the upper member of the Mission Canyon Limestone.

Karst deposits are on the upper surface of the Madison Group in much of Montana. In late Meramec time the Madison sea withdrew from parts of western Montana: the Mission Canyon Limestone, or its equivalent, was subjected to subaerial erosion; and karst deposits were formed prior to deposition of the Kibbey Formation of Chester age. Residual deposits continued to accumulate in Early Pennsylvanian time in southern Montana, and they are included in the basal part of the Amsden Formation.

One or more solution-breccia beds are found throughout southwestern Montana in the Mission Canyon Limestone. These formed between Late Mississippian and early Tertiary time, probably after the Late Cretaceous and early Tertiary uplifts. They mark the stratigraphic positions of evaporites that leached from surface or near-surface exposures; they do not represent an unconformity. The basal anhydrite in the upper member of the Mission Canyon Limestone or in the Charles Formation is a continuous stratigraphic unit throughout much of Montana and Wyoming. Other evaporite units, however, are discontinuous and occupy different stratigraphic positions within the formation.

The solution-breccia beds and the karst-filled deposits are quite similar in color and clayey-siltstone matrix but different in continuity and clay mineralogy. The solution breccia is a heterogeneous mixture of small angular fragments near the base of the beds but grades upward into slightly fractured limestone and dolomite. The karst-filled deposit generally has more matrix and contains fewer chaotically distributed fragments. The upper and lower surfaces of the karst-filled deposit and the upper surface of the solution breccia are poorly defined and are not stratigraphically controlled. The lower surface of the solution breccia, however, is generally sharp, well defined, and continuous. The karst deposit is laterally discontinuous, whereas the solution-breccia units are relatively continuous along the outcrop. Kaolinite is the chief clay mineral in the matrix of the karst-filled deposit, and illite is the chief clay mineral in the matrix of the solution breccia.

INTRODUCTION

Resistant carbonate rocks of the Madison Group form most of the prominent ridges and peaks near Livingston, southwestern Montana. The group is best exposed and most accessible in the east wall of the lower canyon of the Yellowstone River, 3 miles south of Livingston (fig. 1). The Madison, in this area, is a marine-carbonate sequence in which limestone, dolomitic limestone, and dolomite alternate cyclically; it is divided into two formations: the Lodgepole Limestone (in part Kinderhook age and in part Osage age) and the Mission Canyon Limestone (in part Osage age and in part Meramec age) (fig. 2). The Lodgepole is subdivided into a lower, Paine Shale Member, 334 feet thick, and an upper, Woodhurst Limestone Member, 146 feet thick. The Mission Canyon is subdivided into a lower member, 330 feet thick, and an upper member, 326 feet thick. The Madison Group rests apparently conformably on multicolored shale in the upper part of the Three Forks Formation of Late Devonian and early Kinderhook age and is unconformably overlain by grayish-red shale or argillaceous limestone of the Amsden Formation of Pennsylvanian age.

Karst deposits and solution-breccia beds are widespread in the upper part of the Madison Group in Montana and Wyoming, and interbedded red shale is present locally. As knowledge about the Madison carbonate-anhydrite-shale sequence increased, some confusion arose regarding the distinguishing characteristics of the karst deposits and solution-breccia beds. Few localities better exemplify these features as close together for convenient comparison than that of the Madison sequence near Livingston.

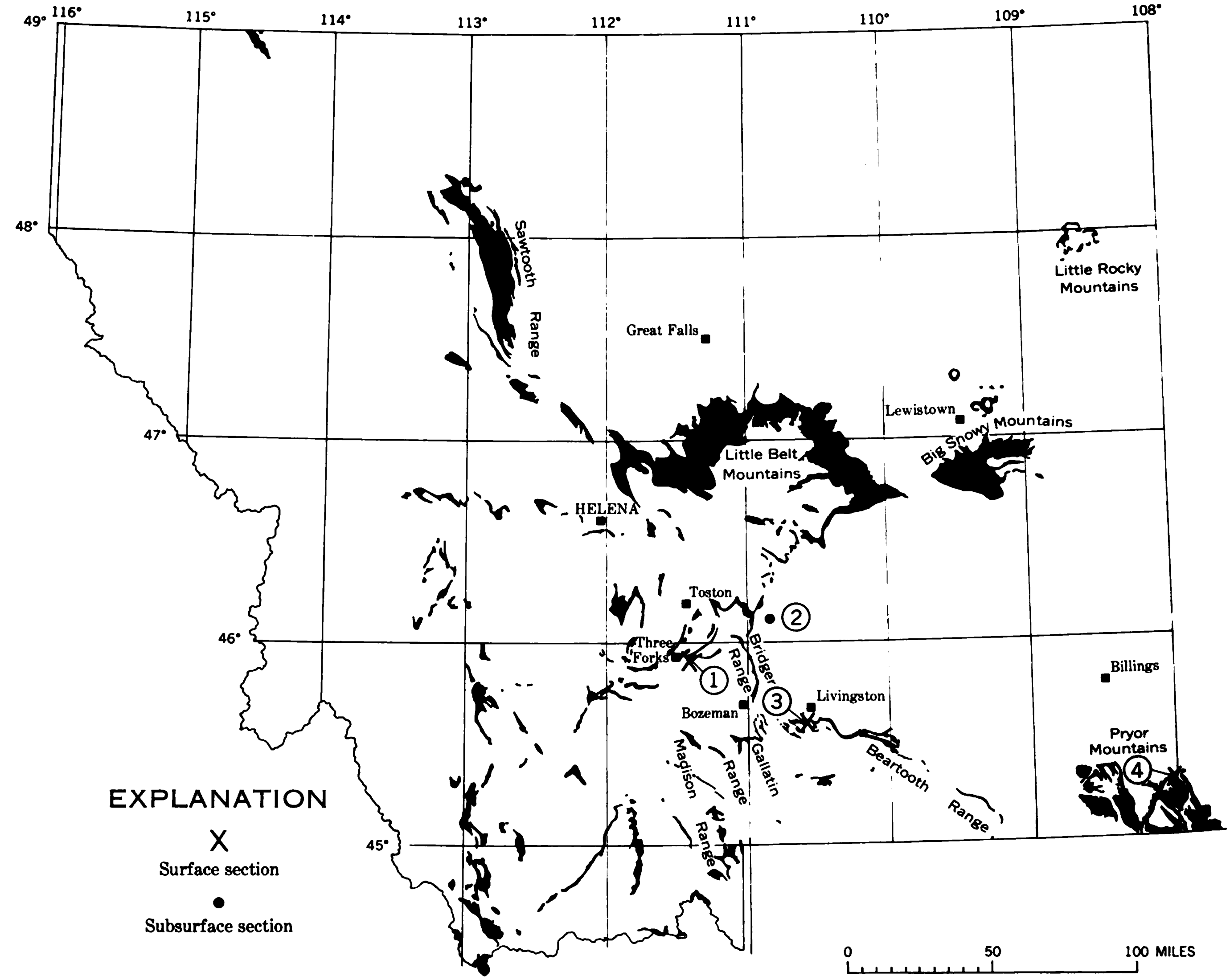


FIGURE 1.—Distribution of major outcrops of Mississippian rocks in western Montana (modified from Ross, Andrews, and Witkind, 1955). Numbered localities refer to measured sections shown in figure 8.

Investigations for this report were made from 1957 through 1961 as a part of the study of the general and economic geology in the area between Livingston and Bozeman, Mont. (Roberts, 1964, a, b, c, d, e, f, g, h; 1966). Some of the conclusions presented here were published earlier (Roberts, 1961), in a preliminary report on the Madison Group near Livingston.

STRATIGRAPHY OF THE MADISON GROUP

DEVELOPMENT OF NOMENCLATURE

Peale (1893, p. 32) divided Carboniferous rocks near Three Forks, Mont. (55 miles northwest of Livingston), into the Madison and Quadrant Formations. He subdivided the Madison Formation, beginning at the base, into "Laminated limestones, Massive limestones, and Jaspery limestones." Iddings and Weed (1894, p. 2) used the name Madison Limestone for the carbonate and shale sequence exposed near Livingston. The Madison Limestone north of Livingston in the Little Belt Mountains was subdivided by Weed (1899, p. 2) into the Paine Shale (for the lower part), the Woodhurst Limestone (for the middle part), and the Castle Limestone (for the upper part); the units are approximate counterparts to Peale's earlier subdivisions. Weed (in Hague, Weed, and Iddings, 1896, p. 4) indicated that the formation was named for the Madison Range, where the limestones are conspicuously exposed. Inasmuch as the report in which Peale (1893) named the Madison Formation was a discussion of the Paleozoic section near Three Forks, acceptance of the Three Forks area as the

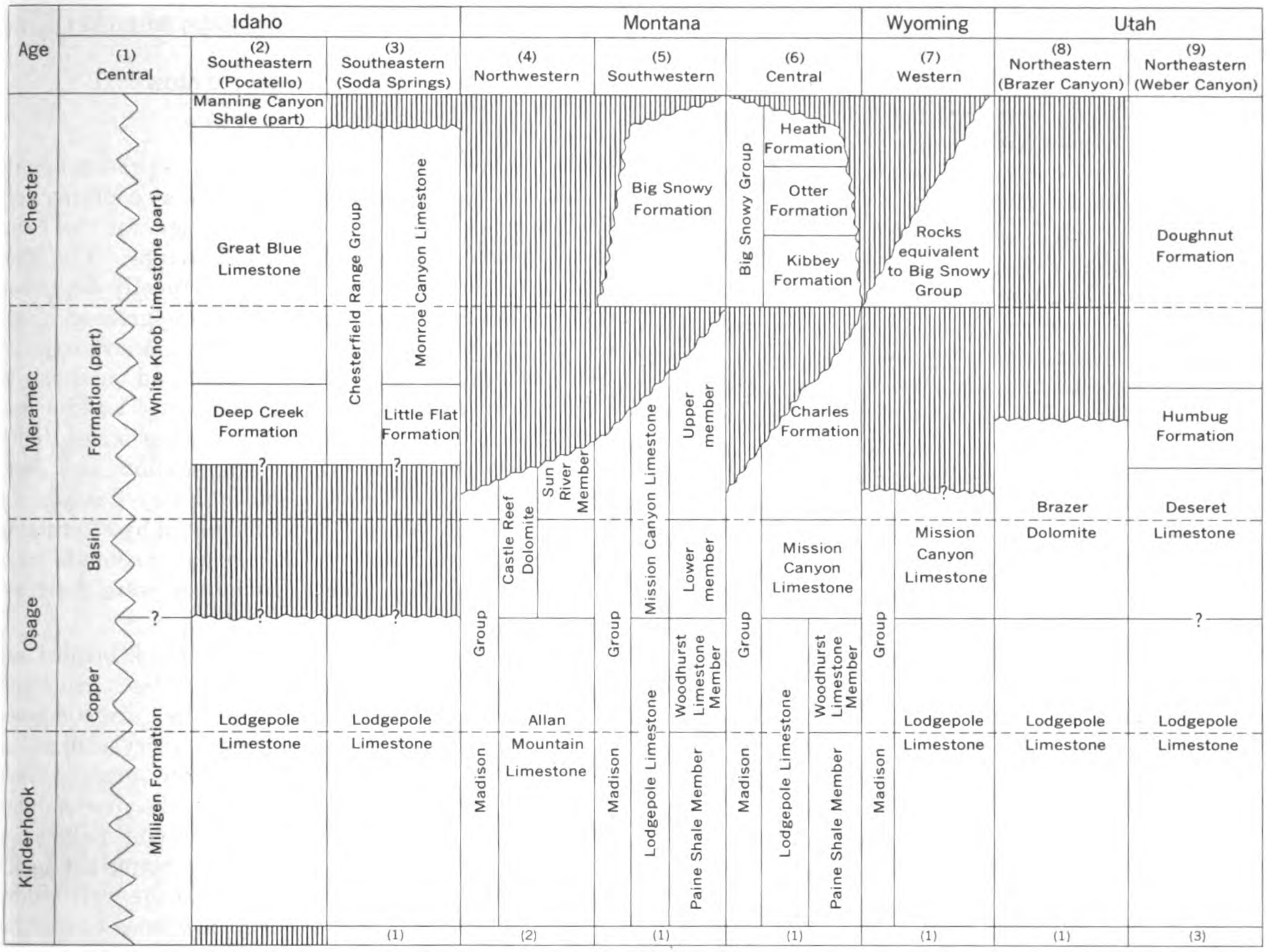


Figure 2.—Correlation and stratigraphic relations of the Madison Group in southwestern Montana and other areas in Montana, Idaho, Wyoming, and Utah. Modified from (1) Ross (1962), (2) Carr and Trimble (1961), (3) Dutro and Sando (1963), (4) Mudge, Sando, and Dutro (1962), (5) Roberts (1961), (6) Mundt (1956), (7) Sando and Dutro 1960, (8) Dutro and Sando (1963), and (9) T. E. Mullens (oral commun., 1963). Numbers in parentheses at bottom of chart indicate (1) Three Forks Formation (part), (2) Exshaw Shale (part), and (3) Three Forks(?) Formation (part).

type area seems reasonable, although it was not so designated in Peale's report.

The Madison Formation in the Little Rocky Mountains region in northern Montana was designated a group and divided into the Lodgepole Limestone and the overlying Mission Canyon Limestone by Collier and Cathcart (1922, p. 173). The Lodgepole corresponds approximately to Peale's laminated limestones and his massive limestones, and the Mission Canyon corresponds approximately to Peale's jaspery limestones.

The nomenclature of the Madison in southwestern Montana was integrated by Sloss and Hamblin (1942, p. 314). They proposed retention of group rank for the Madison and adoption of Weed's Paine Shale and Woodhurst Limestone as members of the Lodgepole Limestone. The stratigraphic section of Madison rocks exposed along the north bank of the Gallatin River in secs. 25 and 26, T. 2 N., R. 2 E., Gallatin County, near Logan, Mont., was interpreted by Sloss and Hamblin (1942, p. 313) as the type Madison section (fig. 1, loc. 1). The Paine Shale and Woodhurst Limestone Members are recognizable in this section, but they are best recognized as two distinct lithologic units in the Little Belt Mountains. These two Lodgepole members are much less distinct near Livingston, southeast of the type Madison section.

A carbonate sequence, including interbedded red shale, anhydrite, gypsum, and salt, that is partly a facies of and partly overlies the Mission Canyon Limestone is present in much of Montana. Seager (1942, p. 864) applied the name Charles to this sequence in southeastern Montana. He suggested (1942, p. 864) that the Charles should perhaps be included with the underlying carbonate rocks as part of the Madison, but he also reasoned that the greater porosity of the limestone beds below the Charles indicated a time break. Seager, therefore, included the Charles in the overlying Big Snowy Group and considered it the basal member. Perry and Sloss (1943, p. 1299) also included the Charles in the Big Snowy Group, assigned the Charles to formational rank, and picked contacts in the California Oil Co. Charles 4 (type) well in sec. 21, T. 15 N., R. 30 E., Petroleum County, Mont. Nordquist (1953, p. 73), however, redefined the Charles by lowering its top to the contact between clastic rocks of the Big Snowy Group and carbonate rocks of the Madison Group. The base of the Charles in west-central Montana (including the section in the type well) is placed at the base of the lowest thick anhydrite bed in a sequence of interbedded carbonate and evaporite beds that overlies the Mission Canyon Limestone. In parts of eastern Montana, where this basal anhydrite is missing, the base of the Charles is generally placed at the base of a persistent dark-gray shale—the Richey shale of subsurface usage. This shale is about 200 feet stratigraphically higher than the basal anhydrite.

Many authors have applied the name Brazer to rocks in the upper part of the Madison Group in parts of Idaho, Montana, Utah, and Wyoming. The type Brazer Limestone correlates approximately with the Mission Canyon Limestone at the type section of the Madison at Logan, Mont. (Sando, Dutro, and Gere, 1959, p. 2755–2761). As a result of their studies of the type Brazer section, Sando, Dutro, and Gere (1959, p. 2768) proposed that the term Brazer Dolomite be restricted to the Mississippian dolomite sequence in the Crawford Mountains, northeastern Utah. The Mission Canyon at the type Madison section contains considerable dolomite (Sando and Dutro, 1960, p. 124), as do the Mission Canyon at Livingston (Roberts, 1961, p. B294) and its equivalent, the Castle Reef Dolomite (fig. 2), in northwestern Montana (Mudge, Sando, and Dutro, 1962, p. 2005–2006). Future study will probably reveal widespread dolomite in this part of the Madison Group; however, in Montana, use of the term Brazer for the dolomitic beds is not recommended.

The Madison Group in the Livingston area includes the Lodgepole Limestone and the Mission Canyon Limestone (fig. 2). The Lodgepole is subdivided (with difficulty) into the Paine Shale Member, which here is predominantly a carbonate sequence, and the Woodhurst Limestone Member. The Mission Canyon is subdivided into upper and lower members (Roberts, 1961, p. B294); the upper member correlates with the Charles Formation.

LITHOLOGIC COMPOSITION

GENERAL FEATURES

The Madison Group near Livingston is predominantly a ridge-forming carbonate sequence that contains very little fine-grained clastic material except for the Paine Shale Member of the Lodgepole Limestone. The Madison is a rhythmically bedded, or cyclically deposited, sequence generally of carbonate and fine-grained clastic rocks. The repetitive units are chiefly massive to thick-bedded limestone in the upper part and medium- to thin-bedded dolomite in the lower part. Laudon and Severson (1953, p. 507) described marine cycles, which they interpreted to be alternating shallow and deep-water deposits, in the Madison at Fairy Lake in the Bridger Range. Marine cycles indicated by alternating deposition of calcium and magnesium carbonate rocks in the Madison Group near Livingston were described by Roberts (1961, p. B294).

The limestone units are massive to thick bedded, are light olive gray (5*Y* 5/2), and contain less than 5 percent insoluble residue. In general, they are composed of microcrystalline calcite in part recrystallized to microspar and sparry calcite showing grain-growth texture. Fossils and fossil debris are the predominant allochemical constituents, and oolites and pellets are lesser constituents. Oolites are more abundant in the massive limestone units, rather than in the well-bedded units, and occur only in massive limestones containing very little insoluble residue. The texture, fossils, oolites, and presence of quartz and heavy-mineral intraclasts suggest that most of the limestone units were deposited in a near-shore high-energy environment. The generalized lithology of the group is shown in figure 3.

The dolomite beds weather more rapidly than the limestone beds and form indentations in the outcrop profile. The dolomite is generally microcrystalline, is varied in color but is commonly light olive gray (5*Y* 6/1) to yellowish brown (10*YR* 6/2), is mostly brecciated, and contains more than 5 percent insoluble residue. The very fine grained dolomite was probably deposited in a low-energy environment in which there were some suspended clay minerals, and the medium-grained dolomite is a secondary-recrystallization product. In most dolomite units the color is slightly darker (light olive gray, 5*Y* 5/2) in the upper part than (light olive gray, 5*Y* 6/1) in the lower part, and the upper part has a slightly more fetid odor than the lower part. Only a few dolomite units contain fossils or fossil fragments.

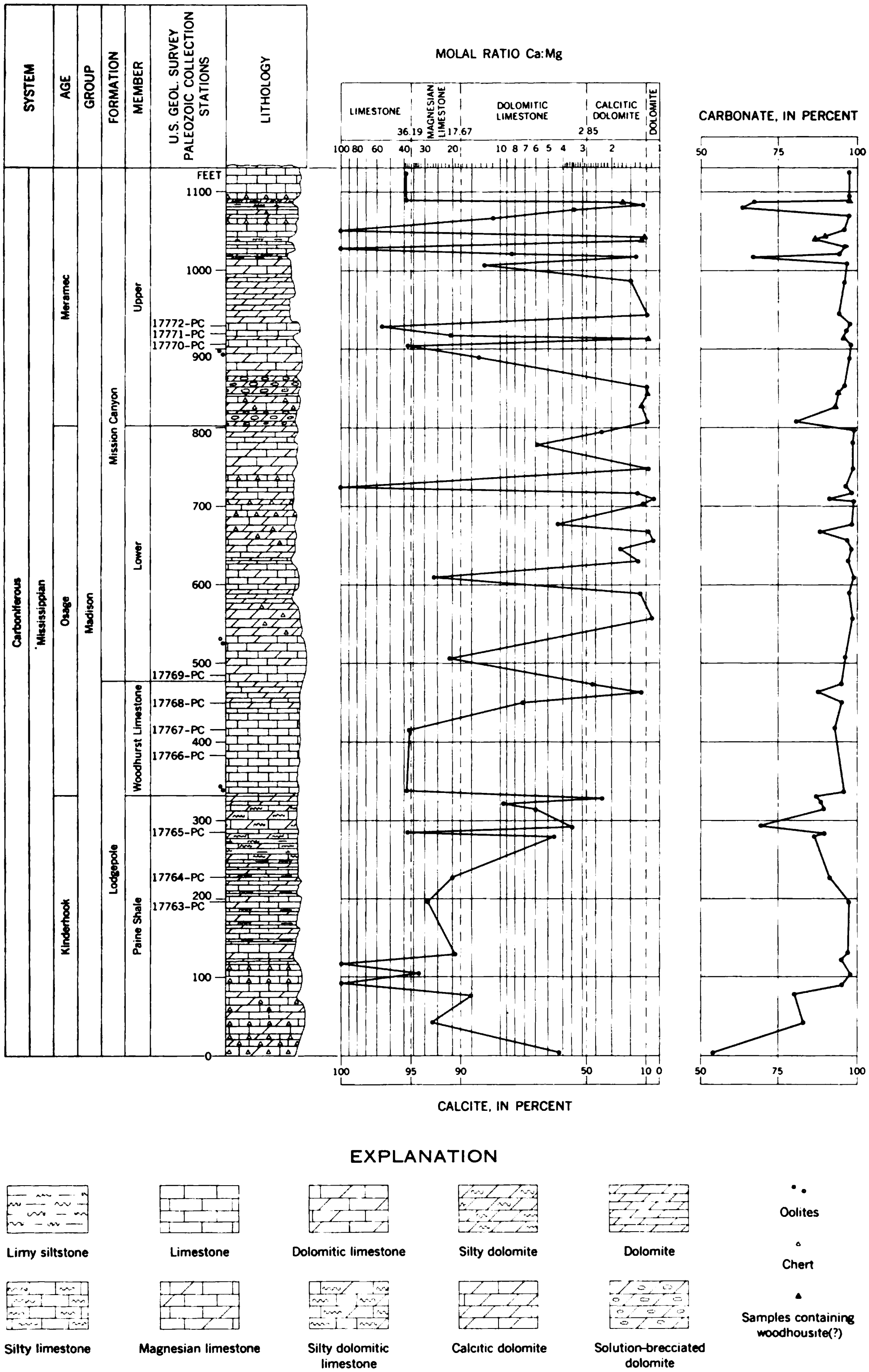


Figure 3.—The Madison Group in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., near Livingston, southwestern Montana. Calcium-magnesium analyses by J. A. Thomas.

787-736 O—65——2

The Madison Group near Livingston is 1,136 feet thick and is subdivided into four members (fig. 3). From oldest to youngest they are the Paine Shale and Woodhurst Limestone Members of the Lodgepole Limestone (480 ft thick) and the lower and upper members of the Mission Canyon Limestone (656 ft thick). The Paine Shale Member is 334 feet thick and consists mostly of medium-bedded to very thin bedded finely to coarsely crystalline limestone, dolomitic and magnesian limestone, and calcitic dolomite that has intercalations of greenish-gray siltstone. The Woodhurst Limestone Member is 146 feet thick and consists of massive to thin-bedded very finely to coarsely crystalline limestone, dolomitic limestone, calcitic dolomite, and dolomite. The lower member of the Mission Canyon Limestone is 330 feet thick and consists mostly of massive very finely to medium-crystalline cherty limestone, magnesian limestone, dolomitic limestone, calcitic dolomite, and dolomite with some solution breccia of dolomite. The upper member is 326 feet thick and consists chiefly of massive finely crystalline limestone, dolomitic limestone, calcitic dolomite, and dolomite with interbedded solution breccia of dolomite and dolomitic grayish-red siltstone.

The type Lodgepole Limestone in the Little Rocky Mountains of north-central Montana consists of 550 feet of thin-bedded carbonate and shale (W. J. Sando and J. T. Dutro, Jr., written commun., 1962). Thin bedding is a typical feature of the Lodgepole in central and parts of western Montana, and many geologists use thin bedding as the criterion for differentiating the Lodgepole from the massive Mission Canyon. Twenty miles west of Livingston, in Bridger Canyon at the south end of the Bridger Range, the Lodgepole Limestone is excellently exposed and exhibits this thin-bedding characteristic (fig. 4).

The type Mission Canyon Limestone in the Little Rocky Mountains consists of 300 feet of massive carbonate (W. J. Sando and J. T. Dutro, Jr., written commun., 1962). At the type locality, beds equivalent to the upper member at Livingston or to the Charles Formation of central Montana were removed by pre-Jurassic erosion. The characteristic massive feature of the Mission Canyon is also widespread in central and western Montana. The excellent exposure in the west wall of the lower canyon of the Yellowstone River near Livingston shows this distinguishing characteristic of the Mission Canyon Limestone (fig. 5).

The upper member of the Mission Canyon Limestone in the Livingston area contains three conspicuous grayish-red dolomitic siltstone beds that can be traced continuously for many miles. One of the siltstones near the top of the upper member is outlined in figure 6 to emphasize its conformable relation with adjacent strata. The siltstone beds are ferruginous and well laminated, and they weather to form indentations between the more resistant limestone beds. These siltstone beds are probably related to the evaporite zones to the north in the upper member of the Mission Canyon Limestone or in the Charles Formation. The red-siltstone beds have been mistaken for matrix materials of karst-filled deposits, which they resemble in color, lithology, and grain size. At the Livingston Mission Canyon section, the stratigraphic relation of the siltstone units to the adjacent beds (figs. 6, 10) and to the karst deposits (fig. 10) is clearly evident.

Mapping the Mission Canyon-Amsden contact in the Livingston area (Roberts, 1964a, b, e, f, g) indicated less than 10 feet of erosional relief on the upper surface of the Mission Canyon (fig. 7). However, numerous northwest-trending joints or normal faults of small displacement in the lower canyon of the Yellowstone

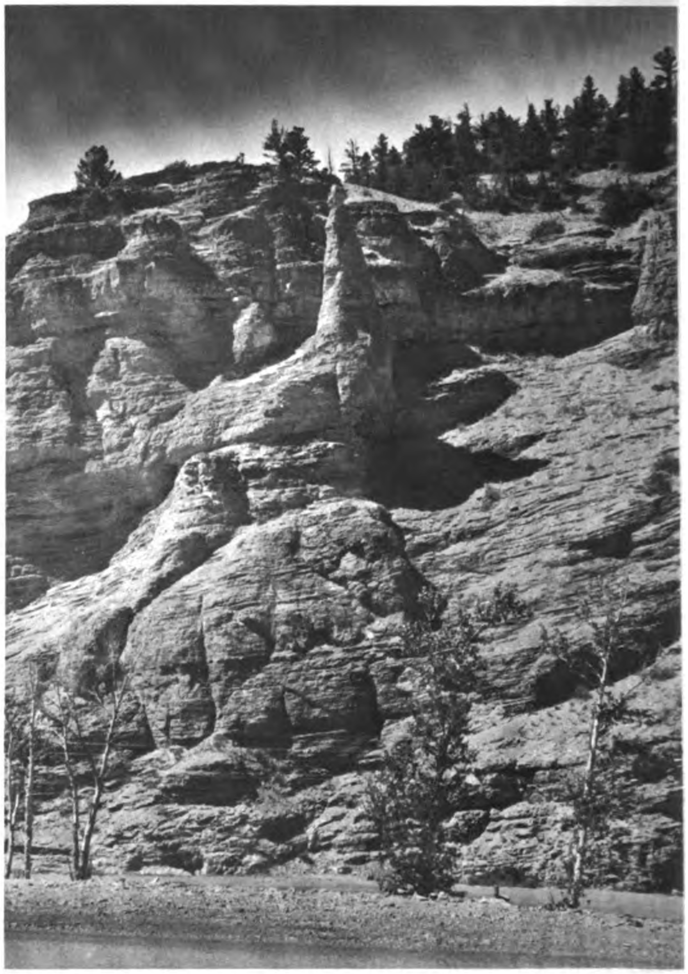


FIGURE 4.—Typical thin-bedded Lodgepole Limestone at the south end of the Bridger Range in Bridger Canyon in sec. 34, T. 1 S., R. 6 E.

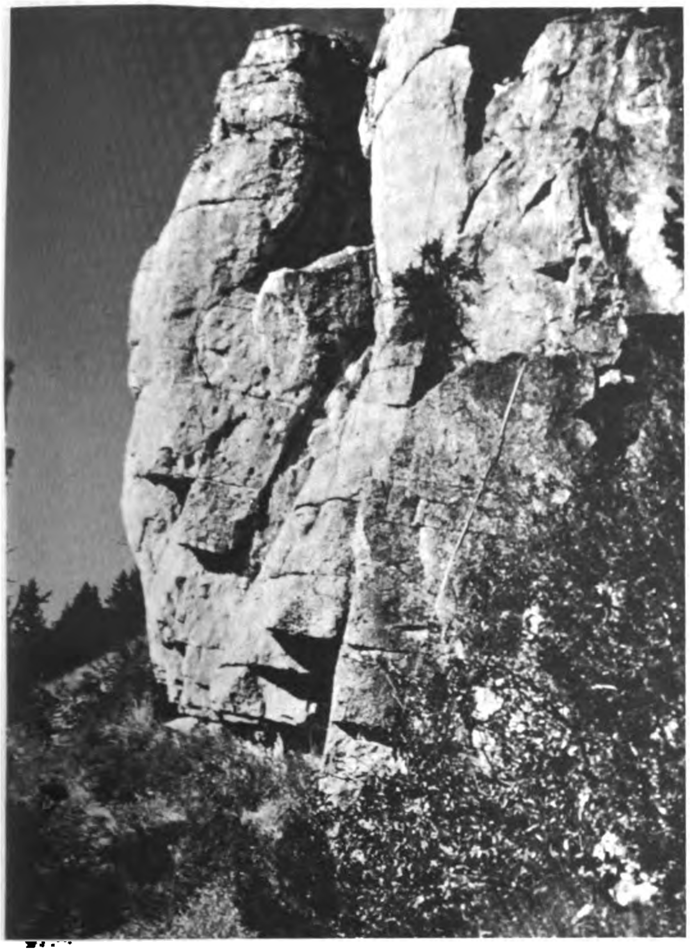


FIGURE 5.—Characteristic massive Mission Canyon Limestone in the south wall of Rocky Creek Canyon in sec. 30, T. 2 S., R. 7 E. Outcrop is approximately 30 feet high.

River cut the beds in the upper member of the Mission Canyon Limestone. Along these joints or faults a karst topography formed (locally to depths of 60 feet) during Early Pennsylvanian time.

Throughout the carbonate sequence at Livingston, chert is common in thin layers along bedding planes or, less commonly, in nodules or lenses. It is particularly abundant in the basal part of the Lodgepole. The thin layers are irregular in cross section and are etched out in relief on weathered surfaces. The proportions of chert and insoluble residue in individual stratigraphic units have no apparent relation. Although chert is particularly abundant in the basal limestone beds, it is also common in dolomite beds higher in this section and does not seem to have been selectively deposited according to rock type.

A dolomitic limestone unit 20 feet thick at the base of the Lodgepole contains about 30 percent brown and yellow chert and is an excellent stratigraphic marker

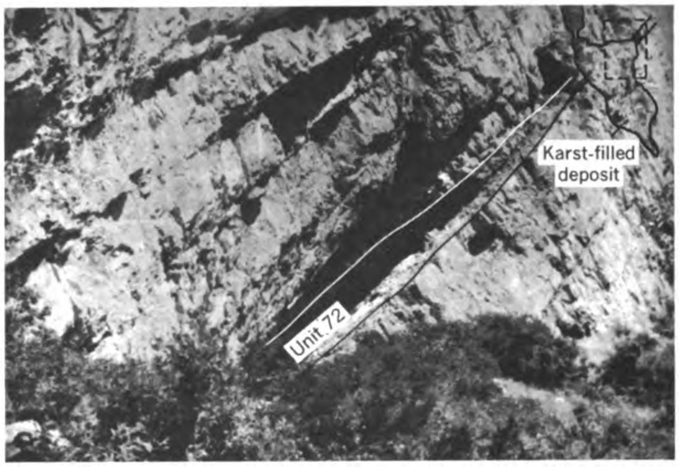


FIGURE 6.—Grayish-red siltstone (unit 72) forming conspicuous indentation between massive limestone 43 feet below the top of the upper member of the Mission Canyon Limestone in SE¼ sec. 35, T. 2 S., R. 9 E. Note outline of karst-filled deposit (shown in fig. 10) in the upper right-hand corner of this photograph.

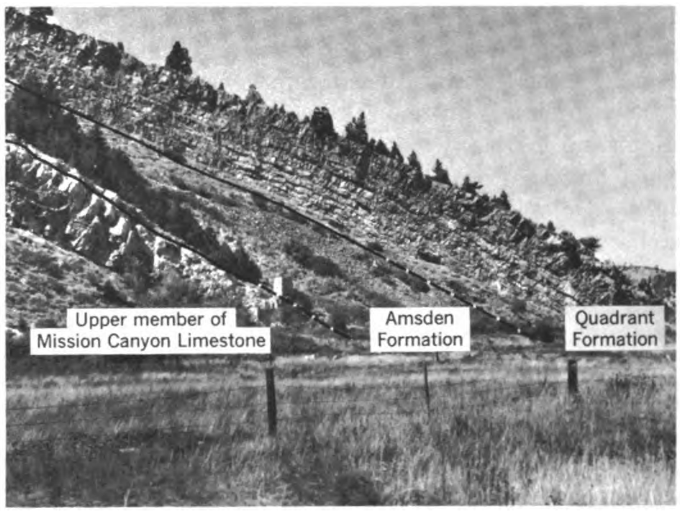


FIGURE 7.—Contact of the upper member of the Mission Canyon Limestone and the overlying Amsden Formation in the S½ sec. 35, T. 2 S., R. 9 E. Note the small amount of erosional relief on the upper surface of the upper member.

in the Livingston area, particularly in structurally complex areas where the Three Forks Formation is faulted or squeezed out. Dark-gray to yellow nodular chert also distinguishes the basal Lodgepole in the Bridger Range (Laudon and Severson, 1953, p. 509). Richards (1957, p. 409) described these basal cherty beds that stand in ledges above the easily eroded Three Forks Shale at Shell Mountain, southeast of Livingston. in ledges above the easily eroded Three Forks Shale Chert is also common in the lower part of the Lodgepole in western Wyoming and northeastern Utah, and in the subsurface of central Montana.

The Mission Canyon Limestone at Livingston contains several laterally continuous breccia beds that I interpret as solution breccia remaining after removal of soluble minerals such as anhydrite or gypsum (see p. B19. Thickness of the upper member of the Mission Canyon Limestone may vary considerably in adjacent surface and subsurface sections. Comparison of thickness, lithology, and fabric on a regional basis suggests that this unit must have been reduced by internal solution during the period of gradual uplift. One example of this change in thickness is shown in figure 8.

DOLOMITE AND DOLOMITIZATION

Dolomite is present throughout the Madison Group at Livingston in amounts that range from a trace to beds composed entirely of layers of dolomite rhombohedra. There are two general groups of dolomite rocks. The larger group has a very finely crystalline (<0.009 mm) matrix with fine- to medium-subhedral to euhedral dolomite crystals dispersed throughout, and the smaller group is varied in crystallinity. In the latter, the dolomite crystals average almost 0.10 mm in diameter and range from very small to 0.20 mm. In comparison, the limestone beds are predominantly microcrystalline-calcite ooze (<0.006 mm in diameter) partially recrystallized to microspar (0.01 mm) and sparry calcite exhibiting grain-growth texture. Dolomitization is confined mainly to the limestone beds of mirocrystalline calcite. Traces of silica, replacing carbonate, are also present; also some dolomite rhombohedrons are partially changed to microcrystalline silica.

The Lodgepole Limestone at Livingston has relatively less dolomite or dolomitic limestone than the Mission Canyon. The calcium: magnesium molal-ratio curve (fig. 3) illustrates a cyclic alternation of carbonate rocks of varied calcium carbonate to magnesium carbonate composition in both formations. The cycles are imperfect or are not apparent in the lower part of the Lodgepole Limestone but are better defined in the younger rocks; in the upper member of the Mission Canyon Limestone, these cycles are conspicuous in the field and are clearly shown in figure 3. Cyclic deposition of limestone and dolomite in Mississippian rocks in the Bridger Range was excellently illustrated by Laudon and Severson (1953, p. 509–512).

The intimate interlayering of thin dolomite and limestone beds, as well as the finer crystallinity of most of the dolomite and the larger content of insoluble residues in the dolomite (fig. 3), suggests that most limestone and uniformly very finely crystalline dolomite were deposited directly from sea water. The nonuniformly medium crystalline dolomite, however, probably recrystallized from a very finely crystalline carbonate. Dolomite rhombohedra transecting fossil and oolite outlines occur in some medium-crystalline dolomite and indicate dolomitization of an original limestone. Hohlt (1948, p. 33) and Chilingar (1956, p. 2492) suggested that the reorientation of calcite crystals facilitates solution migration in carbonate rocks. Hobbs (1957, p. 37) illustrated this point by suggesting a relation between the amount of dolomitization and the types of calcite present. The occurrence of dolomite in the microcrystalline calcite and the absence of trace amounts of dolomite in recrystallized limestone suggest that recrystallization of microcrystalline calcite preceded dolomitization. Dolomitization occurred shortly after lithification and recrystallization but before compaction stresses were great enough to cause reorientation of the microcrystalline calcite. Magnesium-rich solutions were able to penetrate into the microcrystalline calcite but were impeded by decreased porosity and permeability in the coarser grained recrystallized calcite. A few dolomite beds showed gradational enrichment in magnesium coincident with a decrease in size of crystals in some zones or layers.

INSOLUBLE RESIDUES

Differences in insoluble-residue content also characterize the formations and members of the Madison Group, a fact first recognized by Sloss and Hamblin (1942, p. 305). Correlation, based in part on a study of insoluble residues of the Madison Group in north-central Wyoming, was made by Denson and Morrisey (1954, p. 46, 47). Examination of insoluble residues in the Madison at Livingston by Roberts (1961) indicated that the quantity of insoluble residue generally increases as the quantity of magnesium increases. Reports by Roy, Thomas, Weissman, and Schneider (1955), Fairbridge (1957), Dunbar and Rodgers (1957), Bisque and Lemish (1959), and Amsden (1960) discussed or demonstrated this general relation for dolomites.

Insoluble residues in the Madison Group in the lower canyon of the Yellowstone River near Livingston are, mainly, clay minerals, quartz, feldspar (mostly microcline), and chert, and, subordinately, pyrite, magnetite, tourmaline, zircon, garnet, biotite, pyroxene, sphene, barite, hematite, leucoxene, apatite, gold, and marcasite. The most abundant heavy minerals are pyrite and barite, which range from a trace to 90 percent of the total heavy-mineral fraction. Barite was identified by X-ray diffraction. The clay minerals, identified by X-ray diffraction, are illite, kaolinite, and mixed-layer clays. Illite ranges from 60 to 100 percent of the total clay minerals but averages about 90 percent. A few insoluble residues contained as much as 30 percent kaolin-

TABLE 1.—*Grain-size distribution of insoluble residue in carbonate beds of the Lodgepole Limestone and the Mission Canyon Limestone near Livingston, Mont.*

[Analyses by R. F. Gantnier and J. A. Thomas]

Sample	Percent soluble in acid	Percent insoluble for indicated grain size, in millimeters												Heavy minerals in sample (percent)
		4.0	2.0	1.0	0.5	0.25	0.125	0.062	<0.062	0.05	0.005	0.002	<0.002	
MISSION CANYON LIMESTONE														
Upper member														
79	99.3				100.0									0.07
75	99.6								100.0					.12
74	99.1							100.0						.10
73	98.9			0.9	1.3	4.8	11.5	25.6	55.9					.26
72	85.5	[1] 1.3	[1] 0.1			.4	.1	.1		6.2	16.5	10.3	65.0	Trace.
71	[2] 61.1													.04
70	99.7								100.0					
69	99.0						3.4	16.9	79.7					.11
68	99.2						[3] 18.5	[3] 19.7	[3] 61.8					.22
67	92.6									11.0	18.0	21.0	50.0	.04
65	91.3									4.0	17.0	7.0	72.0	Trace.
64	99.3								[4] 100.0					Trace.
62	95.8						.4	6.9	92.7					.02
61	66.8						.2	2.5		11.3	56.4	4.7	24.9	Trace.
59	98.8								100.0					Trace.
53	98.7	[4] 2.2	[4] 2.6	[4] 1.5	6.0	5.2	6.7	15.4	60.3					.12
52	99.4								[3] 100.0					Trace.
50	99.9								100.0					
49	95.9		[1] 36.3		3.3	3.7	[3] 7.3	[3] 13.9	35.5					.61
48	97.6								[3] 100.0					1.86
45	79.3				.04	.1	4.6	12.7	15.3	6.7	41.0	4.7	14.8	Trace.
Lower member														
36	97.3							6.2	93.8					0.06
33	90.4		0.2	1.4	3.2	5.3	11.8	19.1	59.0					.01
LODGEPOLE LIMESTONE														
Woodhurst Limestone Member														
18	89.9									9.0	39.0	1.0	51.0	Trace.
17	95.7	[4] 1.0		[4] 1.2	2.5	2.2	14.3	11.3	67.5					Trace.
16	94.7									9.0	30.0	15.0	46.0	0.01
Paine Shale Member														
12	92.6									14.0	35.0	1.0	50.0	0.01
11	89.8	[4] 0.8	[4] 6.2	[4] 14.3	[4] 12.4	6.5	5.7	11.2	42.8					.01
10 [5]	91.1									8.0	34.0	12.0	46.0	.01
10 [6]	[2] 68.9													Trace.
9	91.1		[4] 10.8	[4] 29.6	[4] 19.7	[4] 4.9	11.0	9.6	14.4					.07
8	90.5									20.0	36.0	15.0	29.0	.01
6 [5]	93.5			.2	.7	2.7	7.5	27.6	61.3					.01
6 [7]	98.3								100.0					.03
4	98.0	[4] 4.0	[4] 3.5	[4] 6.2	[4] 14.7	19.9	17.9	12.7	21.1					.10
3	86.3			4.1	4.0	3.6	10.6	18.6		4.1	34.8	7.1	13.0	Trace.
2	81.0								[1] 100.0					.01
1	50.9	[1] 63.1	[4] 13.1	[4] 6.8	[4] 2.9	1.2	0.8	1.4	10.6					.20

[1] Includes silicified fragments or chert.
[2] Silicified; unable to disaggregate.
[3] Includes petroliferous matter.
[4] Includes fossil fragments.
[5] Near top.
[6] Near bottom.
[7] Near middle.

787-736 O—65——3

ite, but most contained 10 percent or less. About half the insoluble residues from the Mission Canyon contained from a trace to as much as 20 percent mixed-layer clay. Only one insoluble residue from the Lodgepole contained mixed-layer clay. Six insoluble residues from the upper member of the Mission Canyon Limestone contained an unidentified hydrous double salt (probably of the beudantite group) very similar to woodhouseite [$Ca\ Al_3(PO_4)(SO_4)(OH_6)$]. This mineral was present in dolomite, calcitic dolomite, and dolomitic siltstone that contained less than 15 percent insoluble residue. Samples containing this mineral were generally rich in illite or mixed-layer clay and poor in kaolinite. Phosphate and sulfate radicals in this mineral suggest incipient deposition of evaporites.

Grain sizes of the insoluble residues range from less than 0.002 mm to 4.0 mm (table 1). The average grain size of detrital particles is less than 0.062 mm. The larger fragments are silicified carbonate particles or fossil debris.

A comparison of the total insoluble residue and the heavy-mineral fraction indicates that, in general, the ratio of insoluble residue to heavy minerals is high when percentage of insolubles is high, and the ratio is low when the percentage of insolubles is low. This relation suggests that chemical precipitation of iron and sulfate minerals was environmentally controlled, and that the balance of the environment was not upset by the introduction of detrital material. Generally the percentage of insoluble residues and the percentage of heavy minerals increased as the magnesium content of the sea water increased. The presence of pyrite and marcasite suggests slightly reducing conditions. Barite formed presumably when oxidation of some sulfides released sulfate in the presence of barium ions (Pettijohn, 1957, p. 150).

STRATIGRAPHIC SECTION NEAR LIVINGSTON

The following detailed stratigraphic section of the Madison Group was measured by tape and Brunton traverse. Representative samples were collected from about the middle of each lithologic unit for laboratory study. Description of the stratigraphic units combines the megascopic and microscopic examinations. Colors are those given by the National Research Council's "Rock-Color Chart" (Goddard and others, 1948). In referring to the bedding of the rocks, the following standard was used: Massive, greater than 4 feet thick; thick bedded, 2–4 feet; medium bedded, 6 inches–2 feet; thin bedded, 2–6 inches; very thin bedded, ½–2 inches; platy, 1/16–½ inch; and fissile, less than 1/16 inch. In referring to the crystallinity of the carbonate rocks, the following standard was used: Very coarsely crystalline, grains or crystals 1–4 mm in diameter; coarsely crystalline, grains or crystals 0.25–1 mm in diameter; medium crystalline, grains or crystals 0.0625–0.25 mm in diameter; finely crystalline, 0.0156–0.0625 mm in diameter; and very finely crystalline, 0.0039–0.0156 mm in diameter. Terms applied to carbonate rocks are modified from Guerrero and Kenner (1955). Fossils from localities given in the measured section are listed in a separate part of this report.

The section was measured along the east wall of the lower canyon of the Yellowstone River and is considered to be typical of the group in this region.

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.

[Measured by Albert E. Roberts and Cyril J. Galvin, in 1957]

Amsden Formation (Pennsylvanian).

Unconformity: About 1–4 ft of relief on the upper surface of unit 79.

Madison Group (Mississippian):

Mission Canyon Limestone:

Upper member:	Ft	in
79. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); contains endothyrid Foraminifera Plectogyra; forms ridges	22	7
78. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light gray (*N*7); contains lenses and stringers of light-olive-gray (5*Y* 6/1) chert less than 2 in. thick; brecciated locally	4	6
77. Limestone, medium- to thick-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1)	4	7
76. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); lens 1 ft (or less) thick of mottled chert near top	7	5
75. Limestone, medium-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light gray (*N*7)	1	2
74. Dolomite, calcitic, thin- to medium-bedded, medium-crystalline, pale-red (10*R* 6/2); weathers very pale orange (10*YR* 8/2); silty	2	5
73. Limestone, magnesian, irregularly bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light gray (*N*7)		9

Madison Group measured on the east side of the Yellowstone River in Sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

Madison Group (Mississippian)—Continued
Mission Canyon Limestone—Continued
Upper member—Continued

	Ft	*in*
72. Siltstone, dolomitic, thin- to thick-bedded, sandy, grayish-red (10*R* 4/2) and yellowish-gray (5*Y* 7/2); weathers yellowish gray (5*Y* 8/1) to pale yellowish orange (10*YR* 8/6); about 1 in. or less of grayish-yellow-green (5*GY* 7/2) claystone at top; forms conspicuous indentation	3	4
71. Limestone, dolomitic, massive, finely crystalline, silty, light-olive-gray (5*Y* 5/2); weathers medium light gray (*N*6); continuous zone of chert nodules 6½ ft below top	15	6
70. Limestone, dolomitic, thick-bedded, medium-crystalline, pinkish-gray (5*YR* 8/1); weathers pale yellowish brown (10*YR* 6/2); contains several lenses of chert 2–6 in. thick	9	1
69. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); two prominent brown-chert beds generally about 3 in. thick at top of unit	15	9
68. Limestone, medium-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1)	1	1
67. Siltstone, dolomitic, thin-bedded, brittle, mostly grayish-red (10*R* 4/2); lesser amounts yellowish gray (5*Y* 7/2), weathers pinkish gray (5*YR* 8/1); brecciated at base owing to adjustment along bedding planes during folding; unit squeezed to irregular thicknesses	2	7
66. Limestone, medium-bedded, very finely crystalline, light-olive-gray (5*Y* 6/1); weathers light gray (*N*7); contains fine grains of magnetite		8
65. Dolomite, calcitic, very thin bedded to medium-bedded, argillaceous, very finely crystalline, yellowish-gray (5*Y* 7/2); weathers grayish yellow (5*Y* 8/4)	3	5
64. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); oolitic in upper half	13	7

Madison Group Measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

Madison Group (Mississippian)—Continued
Mission Canyon Limestone—Continued
Upper member—Continued

	Ft	*in*
63. Siltstone, irregularly bedded, calcareous, grayish-red (10*R* 4/2), yellow, and pink; fills shallow channels 1–2 ft deep in underlying limestone	1	10
62. Limestone, dolomitic, thick-bedded, finely crystalline, light-olive-gray (5*Y* 6/1); continuous zone of chert nodules near top of unit	2	5
61. Siltstone, dolomitic, medium- to thin-bedded, grayish-red (10*R* 4/2); contains a few thin beds of argillaceous dolomite	2	6
60. Limestone, dolomitic, massive, finely crystalline, arenaceous, mottled grayish-red (10*R* 4/2), pale-red (5*R* 6/2), and pinkish-gray (5*YR* 8/1); weathers grayish pink (5*R* 8/2); contains some silt and fine quartz sand; poorly exposed	28	11
59. Dolomite, calcitic, medium-bedded, finely crystalline, pale-yellowish-brown (10*YR* 6/2); weathers light olive gray (5*Y* 6/1); vuggy; some chert at top of unit	2	0
58. Dolomite, calcitic, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers yellowish gray (5*Y* 7/2); very porous—much of the surface resembles a sponge. Many cavities ranging from a few inches to several feet wide; unit generally brecciated	17	5
57. Limestone, dolomitic, medium-bedded, very finely crystalline, light-olive-gray (5*Y* 5/2); weathers light gray (*N*6); several thin lenses of chert in lower half	3	5
56. Dolomite, irregularly bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers yellowish gray (5*Y* 7/2)	4	6
55. Dolomite, massive to thin-bedded, fine- to medium-crystalline, fossiliferous, brittle, grayish-orange-pink (5*YR* 7/2); weathers very pale orange (10*YR* 8/2); basal 9 ft oolitic; forms conspicuous slabby talus; locally a sandy pebble to cobble conglomerate in the lower 6–12 ft	26	11

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

	Ft	in
Madison Group (Mississippian)—Continued		
Mission Canyon Limestone—Continued		
Upper member—Continued		
54. Limestone, massive, fine- to medium-crystalline, yellowish-gray (5*Y* 7/2); weathers yellowish gray (5*Y* 8/1); fossil locality 17772–PC is the upper 4 ft and fossil locality 17771–PC is the lower 6 ft of unit; upper surface covered with *Syringopora surcularia* Girty; lower 4 ft is dolomitic and bedded; forms prominent ridges	13	5
53. Dolomite, medium- to thin-bedded, finely crystalline, brittle, light-olive-gray (5*Y* 6/1); weathers yellowish gray (5*Y* 7/2); contains broken fossils and a little chert	4	9
52. Limestone, dolomitic in lower half, massive to poorly bedded, fine- to medium-crystalline, pale-yellowish-brown (10*YR* 6/2) to light-olive-gray (5*Y* 6/1); weathers very light olive gray (5*Y* 7/1); oolitic in upper 8 ft; fossil locality 17770–PC upper half of unit; forms prominent ridges; fetid odor	45	8
51. Solution breccia of calcitic finely crystalline light-olive-gray (5*Y* 5/2) dolomite; weathers yellowish gray (5*Y* 7/2; fetid odor	5	0
50. Dolomite, massive, finely crystalline, fossiliferous, light-olive-gray, (5*Y* 5/2); weathers yellowish gray (5*Y* 8/1); unit generally brecciated—probably a solution breccia. Long stringers of chert 2 ft from base	18	3
49. Dolomite, platy, very finely crystalline, light-olive-gray (5*Y* 5/2); weathers yellowish gray (5*Y* 7/2)	2	7
48. Dolomite, calcitic, massive to poorly bedded, medium-crystalline, fossiliferous, pale-yellowish-brown (10*YR* 6/2); weathers yellowish gray (5*Y* 7/2); contains many nodules and stringers of chert	20	0
47. Dolomite, irregularly bedded, very finely crystalline, yellowish-gray (5*Y* 8/1); contains interbedded grayish-yellow-green (5*GY* 7/2) siltstone; unit generally brecciated—probably a solution breccia	3	0
46. Dolomite, irregularly bedded, very finely crystalline, argillaceous, light-olive-gray (5*Y* 5/2); weathers light shades of pink, yellow, and green; locally brecciated—probably a solution breccia	9	6
45. Solution breccia of irregularly very finely crystalline yellowish-gray (5*Y* 8/1) dolomite; weathers shades of green, yellow, and pink; contains subangular to subrounded pebbles, cobbles, and a few boulders of dolomite and chert in interbedded grayish-yellow-green (5*GY* 7/2) siltstone; many cavities ranging from a few inches to several feet wide	5	6
Total, upper member	326	0
Lower member:		
44. Dolomite, calcitic, massive, finely crystalline, pale-yellowish-brown (10*YR* 6/2); weathers very pale orange (10*YR* 8/2); brecciated locally	15	7
43. Dolomite, medium- to thin-bedded, very finely crystalline, light-olive-gray (5*Y* 6/1); weathers yellowish gray (5*Y* 7/2); thin interbeds of limestone	7	6
42. Limestone, dolomitic, massive to faintly stratified, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); contains many chert beds 2 in. or less thick and many chert nodules as much as 6 in. wide; fetid odor; forms ridges	31	6
41. Dolomite, massive to poorly bedded, very finely crystalline, very pale orange (10*YR* 8/2); weathers yellowish gray (5*Y* 8/1); contains solution cavities	6	6
40. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 6/1); weathers light gray (*N*7); prominent chert bed 1½ ft from top; fetid odor; forms ridges	15	3
39. Dolomite, extensively fractured, very finely crystalline, argillaceous; olive-gray (5*Y* 4/1); weathers yellowish gray (5*Y* 7/2); contains solution cavities	1	0

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

	Ft	in
Madison Group (Mississippian)—Continued		
Mission Canyon Limestone—Continued		
Lower member—Continued		
38. Limestone, massive, finely crystalline, light-olive-gray (5*Y* 6/1); weathers light gray (*N*7)	6	2
37. Dolomite, calcitic, massive to medium-bedded, finely crystalline, fossiliferous, pale yellowish-brown (10*YR* 6/2); weathers light gray (*N*7); contains chert nodules; fetid odor	10	5
36. Dolomite, medium-bedded, very finely crystalline, argillaceous, light-olive-gray (5Y 6/1); weathers yellowish gray (5*Y* 8/1); many solution cavities	1	0
35. Dolomite, calcitic, massive to faintly bedded, finely crystalline, light-brownish-gray (5*YR* 6/1); weathers pinkish gray (5*YR* 8/1); contains chert nodules	12	6
34. Limestone, dolomitic, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); sporadic chert nodules and three beds of chert near top of unit; fetid odor	25	8
33. Solution breccia of very finely crystalline light-gray (*N*7) dolomite; weathers very light gray (*N*8); many solution cavities	6	4
32. Limestone, dolomitic, massive, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); contains sporadic chert nodules	5	5
31. Dolomite, medium- to thin-bedded, very finely crystalline, very light olive gray (5*Y* 7/1); weathers yellowish gray (5*Y* 8/1); contains chert lenses and nodules generally 2 in. or less wide; fetid odor	8	1
30. Dolomite, calcitic, massive to thick-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1)	15	1
29. Solution breccia of calcitic light-gray (*N*7) to light-olive-gray (5*Y* 6/1) dolomite; contains chert nodules	6	0
28. Dolomite, calcitic, medium-bedded to very thin bedded, very finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); very silty in the middle and base of unit; contains chert in upper half of unit; fetid odor	6	2
27. Limestone, magnesian, massive, fine- to medium-crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); flat-pebble conglomerate 6 ft from top; chert nodules and lenses; forms ridges	32	1
26. Dolomite, calcitic, thin-bedded to very thin bedded, very finely crystalline, pale-yellowish-brown (10*YR* 6/2); weathers yellowish gray (5*Y* 7/2); readily eroded and is locally cavernous; fetid odor	6	3
25. Limestone, dolomitic, medium-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); conspicuous bed of chert at top of unit	2	7
24. Dolomite, thin-bedded, very finely crystalline, pale-yellowish-brown (10*YR* 6/2); weathers yellowish gray (5*Y* 7/2)	1	5
23. Limestone, dolomitic, thick-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); thin zone of chert in middle of unit	3	3
22. Dolomite, thin-bedded, very finely crystalline, yellowish-gray (5*Y* 7/2); continuous bed of chert at top of unit	3	3
21. Dolomite, massive to medium-bedded, finely crystalline, light-olive-gray (5*Y* 6/1); weathers yellowish gray (5*Y* 8/1); chert stringers and thin beds throughout unit; some flat-pebble conglomerates in upper part; forms ridges	41	6
20. Limestone, magnesian, massive to medium-bedded, medium-crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); oolitic throughout, but more oolitic near top of unit; fossil locality 17769–PC in lower 10 ft of unit; forms very prominent continuous ridges	59	6
Total, lower member	330	0
Total, Mission Canyon Limestone	656	0

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

Madison Group (Mississippian)—Continued
Lodgepole Limestone:
Woodhurst Limestone Member:

	Ft	*in*
19. Dolomite, calcitic, medium- to thin-bedded, coarsely crystalline, fossiliferous (predominantly crinoidal), light-olive-gray (5*Y* 5/2); weathers light gray (*N*7)	4	7
18. Dolomite, calcitic, thin-bedded, very finely crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1)	13	4
17. Limestone, dolomitic, thin-bedded, very coarsely crystalline, light-brownish-gray (5*YR* 6/1); contains moderate red (5*R* 5/4) flecks; weathers yellowish gray (5*Y* 8/1); fossil locality 17768–PC; forms ridges	16	6
16. Limestone, generally thin-bedded in upper 35 ft and massive to thick-bedded in lower 10 ft; alternating light-olive-gray (5*Y* 5/2) and pale-red (10*R* 6/2) beds; weathered surfaces yellowish gray (5*Y* 7/2) to grayish orange pink (5*YR* 7/2); finely to coarsely crystalline; at 23 ft below top several lenticular grayish-red (10*R* 4/2) calcareous-siltstone beds as much as 6 in. thick; some tracks and trails on bedding planes; fossil locality 17767–PC	45	0
15. Limestone, missive to medium-bedded, fine- to medium-crystalline, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); to yellowish gray (5*Y* 8/1); fossil locality 17766–PC	22	8
14. Dolomite, mostly medium- to thin-bedded, thick-bedded in middle of unit, finely crystalline, fossiliferous, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1)	24	6
13. Limestone, massive to thick-bedded upper half of unit and medium- to thin-bedded in lower half, finely to coarsely crystalline, oolitic, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1) tains fossil fragments in lower half of unit; forms ridges	19	5
Total, Woodhurst Limestone Member	146	0

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

Madison Group (Mississippian)—Continued
Lodgepole Limestone—Continued
Paine Shale Member:

	Ft	*in*
12. Dolomite, calcitic, medium-bedded to very thin bedded, very finely crystalline, silty; beds alternately pale yellowish brown (10*YR* 6/2) and pale olive (10*Y* 6/2); weathers mottled to banded light brownish gray (5*YR* 6/1) and yellowish gray (5*Y* 8/1); many thin penecontemporpaneous intraformational breccias; a few fossil tracks and trails	7	3
11. Limestone, dolomitic, thin-bedded, finely to coarsely crystalline, light-olive-gray (5*Y* 6/1); some grayish-red (10*R* 4/2) flecks; weathers light gray (*N*7); contains fossil fragments, tracks, and trails	5	11
10. Limestone, dolomitic, mostly medium- to thin-bedded, locally very thin bedded to platy; finely crystalline, argillaceous, light-olive-gray (5*Y* 5/2) and grayish-red (10*R* 4/2); weathers yellowish gray (5*Y* 7/2) and grayish orange pink (5*YR* 7/2); unit is very conspicuous because of its bedding and weathered color; red beds contain more clay and silt and are slightly more coarsely crystalline than yellowish-gray beds; fossils, tracks, and trails	29	8
9. Limestone, magnesian, thick-bedded, cross-bedded, coarsely crystalline, light-olive-gray (5*Y* 5/2); some grayish-red (10*R* 4/2) flecks; weathers light gray (*N*7); locally contains flat-limestone-pebble conglomerate; fossil locality 17765–PC	3	0
8. Limestone, dolomitic, thin-bedded to platy, finely crystalline, argillaceous, light-olive-gray (5*Y* 5/2); weathers yellowish gray (5*Y* 7/2) and locally grayish orange pink (5*YR* 7/2). grayish red (10*R* 4/2) and greenish gray (5*GY* 6/1); interbedded calcareous greenish-gray (5*G* 6/1) siltstone; some fossil fragments of crinoids and brachiopods; a few thin stringers of chert; generally partly covered	43	11

Madison Group measured on the east side of the Yellowstone River in sec. 35, T. 2 S., R. 9 E., and secs. 1 and 2, T. 3 S., R. 9 E., Park County, Mont.—Continued.

	Ft	in
Madison Group (Mississippian)—Continued		
Lodgepole Limestone—Continued		
Paine Shale Member—Continued		
7. Limestone, dolomitic, medium- to thin-bedded, finely crystalline, light-olive-gray (5*Y* 5/2); weathers yellowish gray (5*Y* 7/2); interbedded calcareous greenish-gray (5*G* 6/1) siltstone; locally becomes intraformational breccia	3	2
6. Limestone, magnesian, medium- to thin-bedded, finely to very coarsely crystalline, light-olive-gray (5*Y* 5/2); weathers grayish orange (10*YR* 7/4) and grayish yellow (5*Y* 7/2); very thin interbedded calcareous greenish-gray (5*G* 6/1) siltstone; few small chert nodules in upper 1 ft of unit; fossil locality 17764–PC between 3 and 4 ft below top of unit; fossil locality 17763–PC 34 ft below top of unit; tracks and trails on siltstone bedding planes; 2-ft-thick flat-siltstone-pebble conglomerate 35 ft below top	105	6
5. Limestone, magnesian, medium-bedded to very thin bedded, finely crystalline, fossiliferous, light-olive-gray (5*Y* 5/2); weathers light olive gray (5*Y* 6/1); contains sporadic small chert nodules and some tracks and trails	6	3
4. Limestone, massive to poorly bedded in upper part and thin- to medium-bedded in lower part, medium- to very coarsely crystalline, fossiliferous, pale-yellowish-brown (10*YR* 6/2), weathers light-olive-gray (5*Y* 6/1); sporadic chert lenses and nodules throughout; oolitic in part; forms prominent cliffs (only unit in measured section that forms a barrier to walking at river's edge)	46	6
3. Limestone, dolomitic, medium- to thin-bedded, finely crystalline, fossiliferous, light-olive-gray (5*Y* 5/2); weathers grayish yellow (5*Y* 7/4); argillaceous; some silty partings	10	0
2. Limestone, magnesian, thick- to thin-bedded, thinner bedded toward base of unit, finely to coarsely crystalline, fossiliferous, pale-yellowish-brown (10*YR* 6/2) to medium-gray (*N*5); weathers light olive gray (5*Y* 6/1) to yellowish gray (5*Y* 7/2); abundant medium-gray (*N*5) chert that weathers medium light gray (*N*6); forms ridges	52	10
1. Limestone, dolomitic, medium- to thin-bedded, mostly fine- to medium-crystalline, basal 3½ ft coarsely crystalline, argillaceous, light-olive-gray (5*Y* 6/1) to medium-dark-gray (*N*4); weathers medium light gray (*N*6), grayish yellow (5*Y* 8/4), grayish orange (10*YR* 7/4), and locally moderate orange pink (5*R* 7/4); many thin shaly partings; abundant crinoidal debris; contains about 30 percent pink, brown, and yellow chert; more chert than any other unit in the Madison Group	20	0
Total, Paine Shale Member	334	0
Total, Lodgepole Limestone	480	0
Total, Madison Group	1,136	0

Three Forks Formation (Mississippian and Devonian).

AGE AND CORRELATION

The Madison Formation, as defined by Peale (1893, p. 33), was assigned by Walcott (in Peale, 1893, p. 39) to lower Carboniferous. Faunas collected from the Madison Limestone in Yellowstone National Park were regarded by Girty (1899, p. 484) as possibly equivalent in age to the major part of the Mississippian but as having their strongest affinities with the Kinderhook. Faunas from the Paine Shale and the Woodhurst Limestone were assigned to the Kinderhook, or Chouteau, by Schuchert and Girty (in Weed, 1900, p. 293).

The Madison of southwestern Montana was summarized by Weller and others (1948, p. 138) as late

Kinderhook and Osage in age. Laudon (1948, p. 295) and Holland (1952, p. 1714) concluded that faunas from the type Madison were indicative of Kinderhook age. Dolomite beds in the upper part of the Mission Canyon in southwestern Montana were assigned by Sloss and Moritz (1951, p. 2157) to the Meramec and tentatively correlated with dolomite beds of the Charles Formation of central Montana. The Lodgepole and Mission Canyon Formations in the Bridger Range represented continuous deposition through all of Kinderhook and perhaps earliest Osage time, according to Laudon and Severson (1953, p. 507). Williams (in Klepper, Weeks, and Ruppel, 1957, p. 18) recognized beds of Meramec age in the upper part of the Mission Canyon in western Montana. The Madison Group, including the type section, was subdivided into faunal zones (Sando and Dutro, 1960, p. 122; Sando, 1960, p. B227); the zones were correlated with late Kinderhook, Osage, and probable Meramec of the type Mississippian.

Mississippian rocks equivalent to the Madison Group (Sando, 1960, p. B226) exposed in the Sawtooth Range of northwestern Montana were named the Hannan Formation by Deiss (1941, p. 1896) and were later described briefly by Deiss (1943, p. 228). He (1933, p. 45) considered this sequence to be almost equivalent in age to the Kinderhook and Osage Series. Sloss and Hamblin (1942, p. 311) concurred with Deiss but recognized that some of the upper limestone beds might be of Late Mississippian age. Sloss and Laird (1945) subdivided the Hannan Formation in northwestern Montana into units MC, MB_2, MB_1, and MA, in ascending order. Unit MC was assigned a Kinderhook age and was considered equivalent to the Paine Shale Member of the Lodgepole Limestone. Unit MB_2 was assigned an Osage age and was considered equivalent to the Woodhurst Limestone Member of the Lodgepole.

Unit MB_1 was assigned an Osage age and was considered equivalent to the Mission Canyon Limestone. Unit MA was assigned a Meramec age and was considered equivalent to the Charles Formation. Mudge, Sando, and Dutro (1962, p. 2003) subdivided the Madison Group in northwestern Montana into the Allan Mountain Limestone (equivalent to the Lodgepole Limestone) and the Castle Reef Dolomite (equivalent to the Mission Canyon Limestone), as shown in figure 2. Unit MA of Sloss and Laird (1945) was named the Sun River Member of the Castle Reef Dolomite by Mudge, Sando, and Dutro (1962, p. 2003).

The Madison Group at Livingston, Mont., is divided into the Lodgepole Limestone, in part of Kinderhook age and in part of Osage age, and the Mission Canyon Limestone, a lower member in part of Osage age and an upper member of Meramec age (fig. 2). Fossils found in the Madison Group in this area include corals, brachiopods, crinoids, and bryozoans. These assemblages are normal-marine benthonic faunas that probably lived in relatively shallow waters on extensive shelves or in epeiric seas (J. T. Dutro, Jr., W. J. Sando, and E. L., Yochelson, written commun., 1958). On the basis of the collections, the Kinderhook-Osage boundary is placed at or near the contact between the Woodhurst Limestone and Paine Shale Members of the Lodgepole (W. J. Sando and J. T. Dutro, Jr., written commun., 1963), and the Osage-Meramec boundary may be placed at the base or at the top of the solution breccia that lies at the base of the upper member of the Mission Canyon Limestone. Inasmuch as the base of the solution breccia is a more consistent stratigraphic horizon than the top, the Osage-Meramec boundary is placed, for convenience, at the base. The solution-breccia units, the grayish-red shale units, the presence in the insoluble residues of minerals that suggest incipient evaporite deposition, and a Meramec fauna seem to establish conclusively the correlation of the upper member of the Mission Canyon Limestone at Livingston with the Charles Formation in central and eastern Montana and unit MA of Sloss and Laird (1945) or with the Sun River Member of the Castle Reef Dolomite in northwestern Montana.

The following fossils, listed in ascending stratigraphic order, were collected from the measured section of the Madison Group near Livingston (see p. B9–B15). Identification of fossil assemblages from this section was made by J. T. Dutro, Jr., W. J. Sando, and E. L. Yochelson (written commun., 1958). Collections from the oldest rocks are listed first. Locality numbers are U.S. Geological Survey upper Paleozoic locality numbers and identify the collections in the measured section (fig. 3; p. B9–B15).

Fossils from the Paine Shale Member of the Lodgepole Limestone:

- Locality 17763–PC:
  - *Orbiculoidea*? sp.
  - *Schuchertella*? sp.
  - *Spirifer* sp. (*centronatus* type)
    - cf. *S. madisonensis* (Girty)
  - *Composita* cf. *C. madisonensis* Girty
  - *Eumetria*? sp.
  - *Platyceras* sp.
- Locality 17764–PC:
  - crinoid arm and fragments, indet.
  - fenestrate bryozoan, indet.
  - *Cystodictya*? sp.
  - *Orthotetes*? sp.
  - *Camarotoechia* cf. *C. herrickana* Girty
  - *Rhynchopora*? sp.
  - "*Productus*" sp. (large)
  - "*Buxtonia*"? sp.
  - "*Productus*" cf. "*P.*" *galletinensis* Girty

Spirifer sp. (*centronatus* type)
Torynifer cf. *T. cooperensis* (Girty)
Punctospirifer cf. *P. solidirostris* (White)
Eumetria cf. *E. verneuiliana* (Hall)
Aviculopinna? sp.
Schizodus? sp.
Bellerophon sp.
Straparollus (*Euomphalus*) sp. cf. *S.* (*E.*) *subplanus* (Hall)
Anematina sp.
Loxonema? sp.

Locality 17765–PC:
crinoidal debris, indet.
platycrinid columnal, indet.
bryozoan fragments, indet.
Schuchertella? sp.
Eumetria sp.

Fossils from the Woodhurst Limestone Member of the Lodgepole Limestone:

Locality 17766–PC:
platycrinid columnals, indet.
Homalophyllites sp.
Vesiculophyllum sp.
Chonetes cf. *C. loganensis* Hall and Whitfield
Linoproductus cf. *L. ovatus* (Hall)
"*Productus*" cf. "*P.*" *gallatinensis* Girty
Spirifer sp. (*centronatus* type)
sp.
Composita? sp.
Platyceras sp.
Straparollus sp.

Locality 17767–PC:
crinoidal debris, indet.
Homalophyllites sp.
Vesiculophyllum sp.
fenestrate bryozoan, indet.
orthotetid brachiopod, indet.
Leptagonia sp.
Chonetes cf. *C. loganensis* Hall and Whitfield
sp. (large form)
productoid brachiopod, indet.
Spirifer sp. (*centronatus* type)
Composita cf. *C. madisonensis* (Girty)
Punctospirifer sp.
Straparollus (*Euomphalus*) sp.

Fossils from the lower member of the Mission Canyon Limestone:

Locality 17768–PC:
Chonetes cf. *C. loganensis* Hall and Whitfield
"*Productus*" cf. "*P.*" *gallatinensis* Girty
Spirifer sp. (*centronatus* type)
cf. *S. madisonensis* Girty
Torynifer? sp.

Locality 17769–PC:
crinoidal debris, indet.
Homalophyllites sp.
Vesiculophyllum? sp.
Spirifer sp.

Fossils from the upper member of the Mission Canyon Limestone:

Locality 17770–PC:
crinoidal debris, indet.
Rhipidomella sp.
Spirifer aff. *S. madisonensis* Girty
sp. (*rowleyi-grimesi* type)
sp. (*centronatus* type)

Locality 17771–PC:
crinoidal debris, indet.
Syringopora surcularia? Girty
Perditocardinia sp. cf. *P. dubia* (Hall)
Rhipidomella? sp.
Spirifer sp. (*rowleyi-grimesi* type)
sp. (*centronatus* type)

Locality 17772–PC:
Syringopora surcularia Girty
aff. *S. surcularia* Girty

SOLUTION BRECCIAS IN THE MISSION CANYON LIMESTONE

A conspicuous solution breccia in the upper member of the Mission Canyon Limestone (fig. 8) throughout southwestern Montana is of great geologic importance in correlation because it is the approximate boundary between rocks of Osage and Meramec age. Near the type locality of the Madison Group, the breccia was first described by Berry (1943, p. 16) as a limestone conglomerate, which he had traced for 10–15 miles. Berry also noted a faunal break and placed an unconformity at the base of the limestone conglomerate, coincident with the base of Peale's (1893) jaspery-limestone unit. This section of Madison rocks, as well as others in the Bridger and Gallatin Ranges, was later described by Leonard (1946), who proposed that the Mission Canyon Limestone be divided into two formations. His division was made at the base of Berry's conglomerate, which Leonard regarded as a basal conglomerate of his Fairy Lake Formation. He noted that the conglomerate contained rounded limestone boulders and angular cherts. Leonard (1946, p. 61) considered the possibility that the conglomerate unit was a solution breccia, but, because of the roundness of the limestone boulders, he preferred the term "conglomerate." Laudon (1948, p. 296) subsequently prepared a diagrammatic sketch illustrating a large unconformity at the base of the conglomerate described by Berry and Leonard. The magnitude of his unconformity was based on his interpretation of the fauna in the lower part of the Mission Canyon as late Kinderhook in age (Laudon, 1948, p. 295).

Laterally continuous collapse-breccia beds in the upper part of the Mission Canyon Limestone in the Elkhorn Mountains were described in Klepper (1950) and Klepper, Weeks, and Ruppel (1957, p. 20). They believed that the breccia formed by penecontemporaneous formation and collapse of solution caverns during a post-Mission Canyon–pre-Amsden erosional period. The stratigraphic persistence of the breccia indicated to them that a widespread withdrawal of seas, due to a slight but uniform uplift, would have exposed a terrain

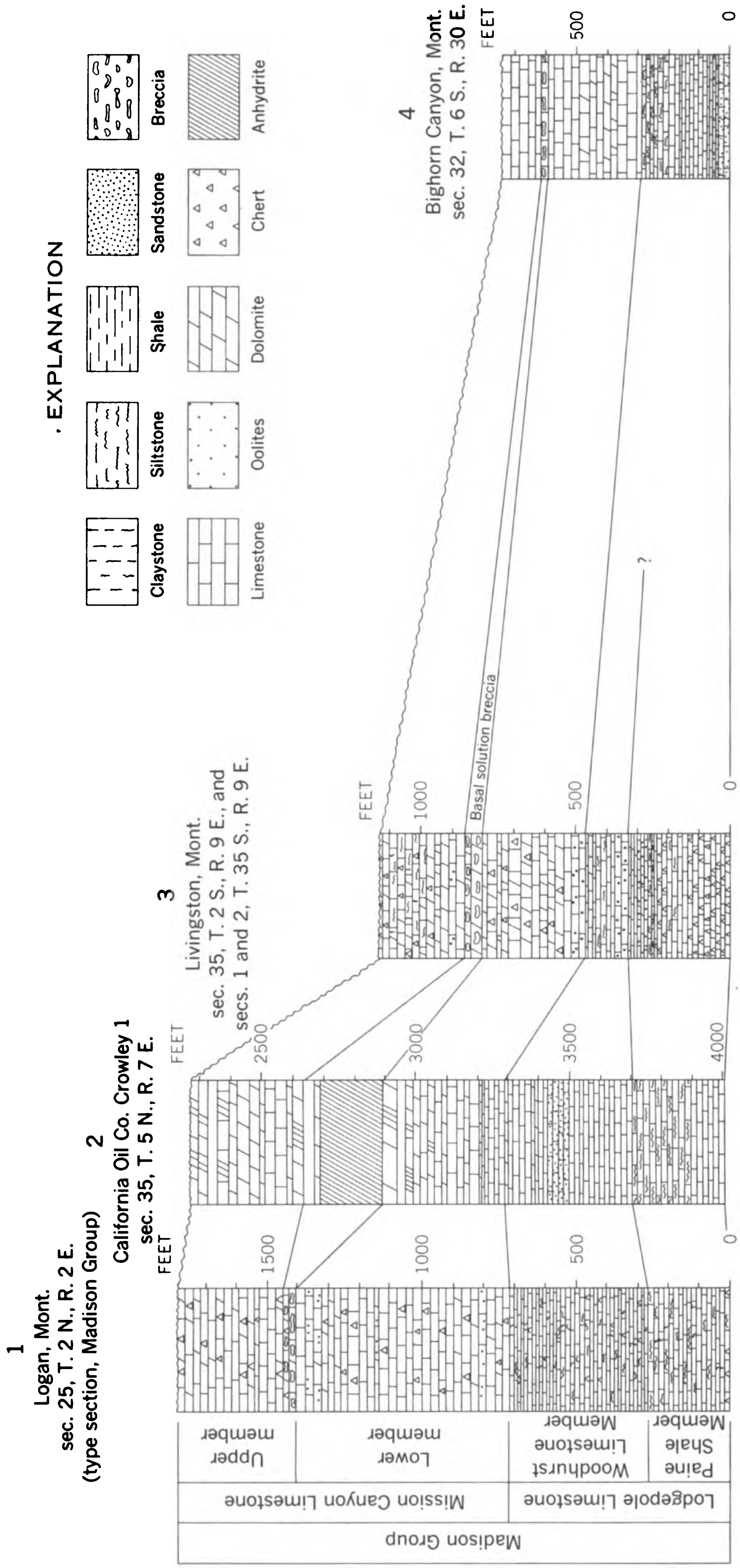


FIGURE 8.—Eastward thinning of the Madison Group and the relations of the basal solution breccia of the upper member of the Mission Canyon Limestone from Logan to Bighorn Canyon, Mont. Localities shown in figure 1.

of negligible relief. They assumed that under such conditions the ground-water level would have been constant and that leaching and ultimate collapse of the roof of the leached zone might have produced a rather continuous breccia zone at about the same stratigraphic horizon.

Severson (1952, p. 33) observed that surface sections of the upper part of the Madison Group in central Montana were thinner than nearby subsurface sections. This difference seemed to indicate that the evaporites in the subsurface sections of the Charles Formation were originally deposited over the mountainous areas but had subsequently been removed by solution. He (1952, p. 37) indicated that the brecciated zones correlated with the anhydrite zones of the subsurface sections and that the subsurface Charles Formation was a correlative of the Mission Canyon Limestone. Sloss (1952, p. 67) briefly summarized the lithology of the Charles Formation and assumed that breccia zones at some localities marked the positions of evaporite beds leached from surface exposures. Laudon and Severson (1953, p. 509–512) remeasured the Fairy Lake section in the Bridger Range and indicated the stratigraphic position of the solution-breccia beds.

In his discussion of the Charles Formation of central Montana, Nordquist (1953, p. 80) pointed out that the basal unit of the formation is generally marked by a massive anhydrite bed that locally is as much as 100 feet thick. In the mountainous areas of central Montana where the upper part of the Madison is exposed, Nordquist observed that the sequence is characterized by several brecciated zones, which he interpreted as having formed by the leaching of evaporite beds.

Denson and Morrisey (1954, p. 46) divided the Mission Canyon Limestone in the Bighorn Basin of Montana and Wyoming and the Wind River Basin of Wyoming into two recognizable members. The base of their upper member is generally marked by a continuous breccia zone, which they (1954, p. 47) could recognize in both the surface and subsurface. They (1954, p. 48) referred to this breccia zone as an intraformational conglomerate.

Andrichuk (1955, p. 2179) correlated the anhydrite beds in the California Oil Co. Crowley 1 well near Ringling, Mont., with solution-breccia beds in the Bridger Range, described by Laudon and Severson (1953, p. 512). In the Fairy Lake section Severson (1952, p. 37) found minor beds of breccia and intraformational conglomerate below the basal breccia of the upper member of the Mission Canyon Limestone. Andrichuk (1955, p. 2173, 2179) identified one of these smaller breccia beds in the lower member of the Mission Canyon as tentatively corresponding to the third evaporite zone in the Mission Canyon of central Montana.

Strickland (1956, p. 54–55) reviewed the work of Mansfield (1927), Love (1939), Berry (1943), Laudon (1948), and Denson and Morrisey (1954) and concluded that the upper member of the Mission Canyon Limestone seems to lie disconformably on the rocks beneath. Later, Norton (1956, p. 54) reviewed the work of Leonard (1946), Laudon and Severson (1953), Denson and Morrisey (1954), and Richards (1955) and concluded that the evidence presented did not substantiate an unconformity but could be explained as collapse brecciation.

Middleton (1961) examined Mission Canyon Limestone sections in the Limestone Hills, on the east flank of the Elkhorn Mountains, and in the Smith River area of the Belt Mountains; reexamined the Fairy Lake section of Leonard (1946), Severson (1952), and Laudon and Severson (1953); and presented a summary description of the solution-breccia beds. He (1961, p. 193) also concluded that the breccia was a solution feature—not formed penecontemporaneously or by metasomatic replacement or by recrystallization.

My recent work supports my earlier conclusions (Roberts, 1961, p. B294) that the laterally continuous breccia beds in the Mission Canyon Limestone at Livingston are solution breccias, and supports my earlier subdivisions (p. B295) of the Mission Canyon Limestone. I (1961, p. B295) subdivided the Mission Canyon into two members, separated at the continuous breccia at the base of the upper member (fig. 9). Several beds of solution breccia are also present in the lower member of the Mission Canyon Limestone, and these should be considered in making regional correlations.

FIGURE 9.—Solution breccia at the base of the upper member of the Mission Canyon Limestone (unit 45) in the SE¼ sec. 35, T. 2 S., R. 9 E.

The solution breccia at the base of the upper member of the Mission Canyon Limestone forms prominent cliffs in the northwestern part of the Yellowstone National Park near Bannock Peak. The breccia, which is continuous throughout the area, is 60 feet thick and 310 feet below the top of the upper member—markedly similar to that in the Livingston section. Similar stratigraphically continuous breccia beds in the Mission Canyon Limestone were observed by Blackstone (1940, p. 594) and by Richards (1955, p. 22) in the Pryor Mountains, Mont., by McMannis (1955, p. 1400) in the Bridger Range, Mont., by Knechtel (1959, p. 735) in the Little Rocky Mountains, and by Robinson (1963, p. 42) in Milligan Canyon near Three Forks, Mont.

KARST DEPOSITS IN THE MISSION CANYON LIMESTONE

Karst deposits are present in the upper part of the Madison Group in southern and western Montana. In south-central Montana, Thom (1923, p. 42) and Thom, Hall, Wegemann, and Moulton (1935, p. 35) discussed the collapsed caverns, or sinkholes, which formed along the joints and bedding planes in the upper part of the Madison prior to the deposition of the overlying Amsden. Karst features at this locality were later illustrated by Richards (1955, pl. 5). Along the north flank of the Beartooth Range, Knappen and Moulton (1930, p. 11) reported a deeply weathered surface and a red residual soil on the top of the Madison. Henbest (1958) briefly described the regional significance of the karst terrane in Upper Mississippian and Lower Pennsylvanian rocks in the Rocky Mountain region.

Sloss and Hamblin (1942, p. 309) stated that in southern Montana the basal sandstones of Chester age (Kibbey Formation) contain fragments of Madison Limestone, and that sandstone of the Amsden Formation fills caverns and solution channels in the Madison. They (1942, p. 318) described the deposits as "a coarse solution breccia formed by the collapse of cavern roofs. These breccias are commonly colored red or maroon by infiltration from the overlying Kibbey or Amsden Formations." Sloss and Hamblin (1942, p. 318) observed that "near Livingston, red Amsden sandstone forms clastic sills and dikes in solution channels cut 200 feet into the Mission Canyon." Laudon (1948, p. 295) referred to these deposits as deep sinkhole-like channels carved into and filled with reworked materials of Mission Canyon. Laudon, Sloss, and Hamblin did not differentiate the red-shale and solution-breccia units in the upper member of the Mission Canyon or the karst deposits of this report.

Scott (1935, p. 1022), Walton (1946, p. 1297), Severson (1952, p. 19), and Miller (1959, p. 13) referred briefly to the erosional unconformity on the upper surface of the Madison in central and southern Montana. Walton (1946, p. 1297) also mentioned pre-Kibbey sinkholes near Riceville, Mont., as evidence of widespread subaerial erosion prior to Kibbey time. Robinson (1963, p. 43) reported a karst topography on the Mission Canyon Limestone near Toston, Mont., where local relief is as much as 100 feet along 300 feet of contact with the basal part of the Big Snowy Group.

Near Livingston the karst deposits (fig. 10) are lithologically very similar to the solution-breccia beds. Both are unstratified fragmental deposits that consist primarily of carbonate rocks and lesser amounts of chert in a matrix that weathers reddish or yellowish gray. The sorting is poor, and the range in size of the fragments is wide. The matrix is composed of in-

FIGURE 10.—Karst-filled deposit in the upper member of the Mission Canyon Limestone in the SE¼ sec. 35, T. 2 S., R. 9 E. Note the crosscutting relation of the karst-filled deposit to the siltstone (unit 72). Base of stadia rod (painted in 1-ft intervals) is 47 feet below top of the upper member.

durated clayey siltstone containing limestone fragments, calcite, and smaller amounts of quartz. The fragments in both the karst deposits and the solution-breccia beds are mostly angular to subangular, although some carbonate fragments are rounded; these rounded fragments may have been shaped by the action of solutions. The chert in both types of deposits is sharply angular.

In the Livingston area there is a significant difference between clay mineralogy of the karst deposits and that of the solution-breccia and red siltstone beds. Kaolinite is the chief clay mineral in the insoluble residues from the karst deposits, and illite is the chief clay mineral in the insoluble residues from the bedded red siltstones and from the basal solution breccia of the upper member of the Mission Canyon Limestone. Illite was also the chief clay mineral in samples collected from the lower, middle, and upper parts of the overlying transgressive Amsden Formation. Thus, though the Amsden and karst deposits are lithologically similar, the predominance of illite in the Amsden and the predominance of kaolinite in the karst deposits indicate entirely different sources and origins. Kaolinite in the karst deposits may have formed during prolonged weathering of an ancient soil that was developed on the uplifted surface of the Mission Canyon. The illite in the siltstone and solution-breccia beds was deposited, but was not necessarily formed, during marine deposition and was not changed during uplift or brecciation.

Severson (1952, p. 35) observed that in a solution-breccia unit there is a definite progression upward from small heterogeneous unsorted material near the base to breccia that is merely a slightly fractured and displaced roof rock near the top. The karst deposits generally have more matrix and fewer chaotically distributed fragments than do the solution-breccia beds (figs. 9, 10). Also, the karst deposits fill cavities or joints that generally widen upward.

The upper and lower surfaces of the karst cavities and the upper surface of the solution-breccia beds are similar in that they are poorly defined and not stratigraphically controlled. The lower surface of the solution-breccia beds, however, is generally a sharp, well-defined laterally continuous boundary. The karst deposits are discontinuous, whereas the solution-breccia beds can be traced continuously for many miles in surface exposures and appear to be continuous with evaporite zones in the subsurface.

Formation of the karst features occurred during post-Mission Canyon (post-Meramec) and pre-Amsden (pre-Early Pennsylvanian) time. The solution-breccia beds probably formed much later, for they are restricted to areas of Late Cretaceous and early Tertiary uplift. In nearby areas that were not uplifted, the evaporite zones in the Madison Group are generally unaltered. For example, about 25 miles northeast of the Fairy Lake section in the Bridger Range, three evaporite zones were penetrated in the California Oil Co. Crowley 1 well (fig. 8, col. 2). Similar conditions exist in the subsurface less than 10 miles from the Big Snowy Mountains. In some localities there may be a surface expression in the younger rocks that would indicate the presence of underlying solution-breccia beds. Such an example of large sinks or depressions due to collapse over major solution zones was observed near Monarch and Riceville, in the Little Belt Mountains, and was described by Severson (1952, p. 41). He noted that rocks as young as Colorado Shale of Cretaceous age were affected in this area and, accordingly, that solution activity at this locality occurred after deposition of the Colorado Shale. Severson's (1952, p. 43) conclusion that the solution-breccia beds were formed during or after Late Cretaceous and early Tertiary uplift therefore seems most reasonable.

REFERENCES

Amsden, T. W., 1960, Hunton stratigraphy, pt. 6 *of* Stratigraphy and paleontology of the Hunton group in the Arbuckle Mountain region: Oklahoma Geol. Survey Bull. 84, 311 p.

Andrichuk, J. M., 1955, Mississippian Madison group stratigraphy and sedimentation in Wyoming and southern Montana: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 11, p. 2170–2210.

Berry, G. W., 1943, Stratigraphy and structure at Three Forks, Montana: Geol. Soc. America Bull., v. 54, no 1, p. 1–29.

Bisque, R. E., and Lemish, John, 1959, Insoluble residue–magnesium content relationship of carbonate rocks from the Devonian Cedar Valley Formation [Iowa]: Jour. Sed. Petrology, v. 29, no. 1, p. 73–76.

Blackstone, D. L., Jr., 1940, Structure of the Pryor Mountains, Montana: Jour. Geology, v. 48, no. 6, p. 590–618.

Carr, W. J., and Trimble, D. E., 1961, Upper Paleozoic rocks in the Deep Creek Mountains, Idaho, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–C, p. C181–C184.

Chillingar, G. V., 1956, Use of Ca-Mg ratio in porosity studies: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 10, p. 2489–2493.

Collier, A. J., and Cathcart, S. H., 1922, Possibility of finding oil in loccolithic domes south of the Little Rocky Mountains, Montana: U.S. Geol. Survey Bull. 736–F, p. 171–178 [1923].

Deiss, C. F., 1933, Paleozoic formations of northwestern Montana: Montana Bur. Mines and Geology Mem. 6, 51 p.

——— 1941, Structure of central part of Sawtooth Range, Montana [abs.]: Geol. Soc. America Bull., v. 52, no. 12, pt. 2, p. 1896–1897.

——— 1943, Stratigraphy and structure of southwest Saypo quadrangle, Montana: Geol. Soc. America Bull., v. 54, no. 2, p. 205–262.

Denson, M. E., Jr., and Morrisey, N. S., 1954, Subsurface correlations within the Madison Group, Big Horn and Wind River Basins [Wyoming], *in* Billings Geol. Soc. Guidebook 5th Ann. Field Conf.: p. 44–49.

Dunbar, C. O., and Rodgers, John, 1957, Principles of stratigraphy: New York, John Wiley & Sons, 356 p.

Dutro, J. T., Jr., and W. J., 1963, New Mississippian formations and faunal zones in Chesterfield Range, Portneuf quadrangle, southeast Idaho: Am. Assoc Petroleum Geologists Bull., v. 47, no. 11, p. 1963–1986.

Fairbridge, R. W., 1957, The dolomite question, *in* Le Blanc, R. J., and Breeding, J. G., eds., Regional aspects of carbonate deposition—a symposium: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 5, p. 125–178.

Girty, G. H., 1899, Devonian and Carboniferous fossils, *in* Geology of the Yellowstone National Park: U.S. Geol. Survey Mon. 32, pt. 2, chap. 12, sec. 2, p. 479–599.

Goddard, E. N., chm., and others, 1948, Rock-color chart: Washington, Natl. Research Council, 6 p.

Guerrero, R. G., and Kenner, C. T., 1955, Classification of Permian rocks of western Texas by a versenate method of chemical analysis: Jour. Sed. Petrology, v. 25, no. 1, p. 45–50.

Hague, Arnold, Weed, W. H., and Iddings, J. P., 1896, Yellowstone National Park sheets [Wyoming]: U.S. Geol. Survey Geol. Atlas, Folio 30, 6 p.

Henbest, L. G., 1958, Significance of karst terrane and residuum in Upper Mississippian and Lower Pennsylvanian rocks, Rocky Mountain region, *in* Wyoming Geol. Assoc. Guidebook 13th Ann. Field Conf., Powder River Basin: p. 36–37.

Hobbs, C. R. B., 1957, Petrography and origin of dolomite-bearing carbonate rocks of Ordovician age in Virginia: Virginia Polytechnic Inst. Bull., Eng. Expt. Sta. Ser. 116, v. 50, no. 5, 128 p.

Hohlt, R. B., 1948, The nature and origin of limestone porosity: Colorado School Mines Quart., v. 43, no. 4, 51 p.

Holland, F. D., Jr., 1952, Stratigraphic details of Lower Mississippian rocks of northeastern Utah and southwestern Montana: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 9, p. 1697–1734.

Iddings, J. P., and Weed, W. H., 1894, Livingston atlas sheet [Montana]: U.S. Geol. Survey Geol. Atlas, Folio 1, 5 p.

Klepper, M. R., 1950, A geologic reconnaissance of parts of Beaverhead and Madison Counties, Montana: U.S. Geol. Survey Bull., 969–C, p. 55–85 [1951].

Klepper, M. R., Weeks, R. A., and Ruppel, E. T., 1957, Geology of the southern Elkhorn Mountains, Jefferson and Broadwater Counties, Montana: U.S. Geol. Survey Prof. Paper 292, 82 p. [1958].

Knappen, R. S., and Moulton, G. F., 1930, Geology and mineral resources of parts of Carbon, Big Horn, Yellowstone, and Stillwater Counties, Montana: U.S. Geol. Survey Bull. 822–A, p. 1–70.

Knechtel, M. M., 1959, Stratigraphy of the Little Rocky Mountains and encircling foothills, Montana: U.S. Geol. Survey Bull. 1072–N, p. 723–752 [1960].

Laudon, L. R., 1948, Osage-Meramec contact, *in* Weller, J. M., ed., Symposium on problems of Mississippian stratigraphy and correlation: Jour. Geology, v. 56, no. 4, p. 288–302.

Laudon, L. R., and Severson, J. L., 1953, New crinoid fauna, Mississippian, Lodgepole formation, Montana: Jour. Paleontology, v. 27, no. 4, p. 505–536.

Leonard, J. R., 1946, The Mississippian stratigraphy of the Gallatin Basin, Montana: Lawrence, Kansas Univ. unpub. M.S. thesis.

Love, J. D., 1939, Geology along the southern margin of the Absaroka Range, Wyoming: Geol. Soc. America Spec. Paper 20, 134 p.

McMannis, W. J., 1955, Geology of the Bridger Range, Montana: Geol. Soc. America Bull., v. 66, no. 11, p. 1385–1430.

Mansfield, G. R., 1927, Geography, geology, and mineral resources of part of southeastern Idaho: U.S. Geol. Survey Prof. Paper 152, 453 p.

Middleton, G. V., 1961, Evaporite solution breccias from the Mississippian of southwest Montana: Jour. Sed. Petrology, v. 31, no. 2, p. 189–195.

Miller, R. N., 1959, Geology of the south Moccasin Mountains, Fergus County, Montana: Montana Bur. Mines and Geology Mem. 37, 44 p.

Mudge, M. R., Sando, W. J., and Dutro, J. T., Jr., 1962, Mississipian rocks of Sun River Canyon area, Sawtooth Range, Montana: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 11, p. 2003–2018.

Mundt, P. A., 1956, Heath-Amsden strata in central Montana: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 8, p. 1915–1934.

Nordquist, J. W., 1953, Mississippian stratigraphy of northern Montana, *in* Billings Geol. Soc. Guidebook 4th Ann. Field Conf.: p. 68–82.

Norton, G. H., 1956, Evidences of unconformity in rocks of Carboniferous age in central Montana, *in* Billings Geol. Soc. Guidebook 7th Ann. Field Conf.: p. 52–66.

Peale, A. C., 1893, The Paleozoic section in the vicinity of Three Forks, Montana: U.S. Geol. Survey Bull. 110, 56 p.

Perry, E. S., and Sloss, L. L., 1943, Big Snowy group, lithology and correlation in the northern Great Plains: Am. Assoc. Petroleum Geologists Bull., v. 27, no. 10, p. 1287–1304.

Pettijohn, F. J., 1957, Sedimentary rocks, 2d ed.: New York, Harper & Bros., 718 p.

Richards, P. W., 1955, Geology of the Bighorn Canyon-Hardin area, Montana and Wyoming: U.S. Geol. Survey Bull. 1026, 93 p. [1956].

——— 1957, Geology of the area east and southeast of Livingston, Park County, Montana: U.S. Geol. Survey Bull. 1021–L, p. 385–438.

Roberts, A. E., 1961, Insoluble residues and Ca:Mg ratios in the Madison group, Livingston, Montana, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–B, p. B294–B296.

——— 1964a, Geology of the Brisbin quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–256.

——— 1964b, Geology of the Chimney Rock quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–257.

——— 1964c, Geology of the Hoppers quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–258.

——— 1964d, Geologic map of the Livingston quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–259.

——— 1964e, Geologic map of the Maxey Ridge quadrangle, Montana: U.S. Geol. Survey Misc., Geol. Inv. Map I–396.

——— 1964f, Geologic map of the Fort Ellis quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I–397.

——— 1964g, Geologic map of the Mystic Lake quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I–398.

——— 1964h, Geologic map of the Bozeman Pass quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I–399.

——— 1966, Geology and coal resources of the Livingston coal field, Gallatin and Park Counties, Montana: U.S. Geol. Survey Prof. Paper 526–A.

Robinson, G. D., 1963, Geology of the Three Forks quadrangle, Montana: U.S. Geol. Survey Prof. Paper 370, 143 p.

Ross, C. P., 1962, Upper Paleozoic rocks in central Idaho: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 3, pt. 1, p. 384–405.

Ross, C. P., Andrews, D. A., and Witkind, I. J., 1955, Geologic map of Montana: U.S. Geol. Survey.

Roy, C. J., Thomas, L. A., Weissmann, R. C., and Schneider, R. C., 1955, Geologic factors related to quality of limestone aggregates: Highway Research Board Proc., v. 34, p. 400–411.

Sando, W. J., 1960, Distribution of corals in the Madison Group and correlative strata in Montana, western Wyoming, and northeastern Utah, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400–B, p. B225–B227.

Sando, W. J., and Dutro, J. T., Jr., 1960, Stratigraphy and coral zonation of the Madison Group and Brazer Dolomite in northeastern Utah, western Wyoming, and southwestern Montana, *in* Overthrust belt of southwestern Wyoming and adjacent areas: Wyoming Geol. Assoc. Guidebook 15th Ann. Field Conf., p. 117–126.

Sando, W. J., Dutro, J. T., Jr., and Gere, W. C., 1959, Brazer Dolomite (Mississippian), Randolph quadrangle, northeast Utah: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 12, p. 2741–2769.

Scott, H. W., 1935, Some Carboniferous stratigraphy in Montana and northwestern Wyoming: Jour. Geology, v. 43, no. 8, pt. 2, p. 1011–1032.

Seager, O. A., 1942, Test on Cedar Creek anticline, southeastern Montana: Am. Assoc. Petroleum Geologists Bull., v. 26, no. 5, p. 861–864.

Severson, J. L., 1952, A comparison of the Madison Group (Mississippian) with its subsurface equivalents in central Montana: Madison, Wisconsin Univ. unpub. Ph. D. thesis (available on microfilm).

Sloss, L. L., 1952, Introduction to the Mississippian of the Williston basin, *in* Billings Geol. Soc. Guidebook 3d Ann. Field Conf.: p. 65–69.

Sloss, L. L., and Hamblin, R. H., 1942, Stratigraphy and insoluble residues of Madison Group (Mississippian) of Montana: Am. Assoc. Petroleum Geologists Bull., v. 26, no. 3, p. 305–335.

Sloss, L. L., and Laird, W. M., 1945, Mississippian and Devonian stratigraphy of northwestern Montana: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart 15.

Sloss, L. L., and Moritz, C. A., 1951, Paleozoic stratigraphy of southwestern Montana: Am. Assoc. Petroleum Geologists Bull., v. 35, no. 10, p. 2135–2169.

Strickland, J. W., 1956, Mississippian stratigraphy, western Wyoming, *in* Wyoming Geol. Assoc. Guidebook 11th Ann. Field Conf.: p. 51–57.

Thom, W. T., Jr., 1923, Oil and gas prospects in and near the Crow Indian Reservation, Montana: U.S. Geol. Survey Bull. 736–B, p. 35–53.

Thom, W. T., Jr., Hall, G. M., Wegemann, C. H., and Moulton, G. F., 1935, Geology of Big Horn County and the Crow Indian Reservation, Montana: U.S. Geol. Survey Bull. 856, 200 p.

Walton, P. T., 1946, Ellis, Amsden, and Big Snowy Group, Judith Basin, Montana: Am. Assoc. Petroleum Geologists Bull., v. 30, no. 8, pt. 1, p. 1294–1305.

Weed, W. H., 1899, Description of the Little Belt Mountains quadrangle [Montana]: U.S. Geol. Survey Geol. Atlas, Folio 56.

——— 1900, Geology of the Little Belt Mountains, Montana: U.S. Geol. Survey 20th Ann. Rept., pt. 3, p. 257–461.

Weller, J. M., chm., and others, 1948, Correlation of the Mississippian formations of North America [chart 5]: Geol. Soc. America Bull., v. 59, no. 2, p. 91–196.

Cretaceous and Early Tertiary Depositional and Tectonic History of the Livingston Area, Southwestern Montana

GEOLOGICAL SURVEY PROFESSIONAL PAPER 526-C

Cretaceous and Early Tertiary Depositional and Tectonic History of the Livingston Area, Southwestern Montana

By ALBERT E. ROBERTS

GEOLOGY OF THE LIVINGSTON AREA, SOUTHWESTERN MONTANA

GEOLOGICAL SURVEY PROFESSIONAL PAPER 526-C

A study of the character of the sedimentary rocks—their texture, variation in composition, age assignments, regional correlation, and tectonic implications

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1972

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402. (paper cover)
Stock Number 2401–0201

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

CRETACEOUS AND EARLY TERTIARY DEPOSITIONAL AND TECTONIC HISTORY OF THE LIVINGSTON AREA, SOUTHWESTERN MONTANA

By Albert E. Roberts

ABSTRACT

Cretaceous and lower Tertiary rocks exposed near Livingston, southwestern Montana, form a marine and continental sequence of sedimentary and volcanic rocks more than 20,000 feet thick. Correlation of these rocks with those in other areas of Montana and Wyoming is based on recent studies of structure, facies relations, and paleontology of the Livingston sequence. The Lower Cretaceous Series is 1,250 feet thick and includes the Kootenai Formation, the Thermopolis Shale, and the Mowry Shale. The Upper Cretaceous Series is 10,830 feet thick and is correlated with or consists of the Frontier Formation, Cody Shale, Telegraph Creek Formation, Eagle Sandstone, Cokedale Formation, Miner Creek Formation, Billman Creek Formation, Hoppers Formation, and the basal 980 feet of the Fort Union Formation. The Paleocene Series consists of the upper 5,635 feet of the Fort Union Formation. The Eocene Series is more than 1,700 feet thick and consists of the Crandall(?) Conglomerate, Cathedral Cliffs(?) Formation, and the Golmeyer Creek and Hyalite Peak Volcanics.

The Cretaceous and Tertiary tectonic history of the Livingston area is complex. Uplift to the west at the close of the Jurassic initiated the continental deposition of the Kootenai Formation.

From the end of Kootenai time through Eagle time, epicontinental Cretaceous seas transgressed and regressed across the relatively stable Livingston area. Late in the Coniacian or early Santonian Stage of Late Cretaceous time, epeirogenic arching began in western Montana, and the Eagle sea regressed to the east. Beds as old as the Lodgepole Limestone of Early Mississippian age were exposed by erosion. Periodic uplift and erosion were accompanied by the most extensive volcanism that has occurred in western Montana. Contemporaneously, the Livingston area was gradually warped downward as part of the Crazy Mountains basin, and more than 13,000 feet of sedimentary rock—derived predominantly from the western volcanic rocks—was deposited as the Livingston Group and the Fort Union Formation. This continuous sequence of continental rocks grades laterally to the east and northeast beyond the Livingston area into finer grained marine and nonmarine units. Subsidence and deposition were greater in the western part of the basin than in the eastern part and were accelerated in both parts in late Campanian and Maestrichtian time.

During deposition of the Fort Union Formation, the borderland in the area now occupied by the northern part of the Gallatin Range and the Bridger Range continued to rise and thereby restricted the western limit of the Fort Union of Montana to the longitude of the Crazy Mountains basin. Sedimentary units of the Fort Union were folded, probably near the close of the Paleocene Epoch. Major thrusting then occurred in areas bordering the thickest deposits. South of Livingston the ancestral Gallatins, which formed the southwestern edge of the basin, were covered in early Eocene time by conglomeratic units equivalent to the Crandall Conglomerate and the Cathedral Cliffs Formation of northwestern Wyoming. None of these units extended northward into the basin. These Eocene deposits remain relatively undeformed in contrast to the underlying folded formations, a fact indicating that the last major period of folding for this area occurred near the end of Paleocene or the beginning of Eocene time. The conglomeratic units are overlain by Eocene volcanic rocks—generally flows, flow breccias, and mudflows—that correlate with the oldest volcanic units in the Yellowstone Park region.

Both the Livingston Group and the Fort Union Formation at Livingston vary rapidly in lithology, vertically and laterally; these rocks probably represent fluvial channel systems associated with extensive flood-plain deposits near sea level, judging by their similarities to deposits on present-day flood plains. The major source of these sediments was west of the Crazy Mountains basin; lesser amounts of sediment came from areas northwest and south of the basin. The character of the rocks at the base of the Fort Union differs markedly from that of rocks of the underlying Livingston Group. The conglomerates in the Livingston Group are composed almost entirely of volcanic rocks like those presently exposed in the Elkhorn Mountains of western Montana, whereas the conglomerates in the Fort Union contain igneous, metamorphic, and sedimentary rock fragments derived from rocks of Precambrian, Paleozoic, and Mesozoic age. This significant change in provenance suggests a closer source area for the Fort Union and one in which there were greater dissection and more vigorous erosion than for the earlier deposited Livingston Group.

INTRODUCTION

LOCATION

The area of this report, hereafter referred to as the Livingston area, is at the junction of the northern end of the Gallatin Range, the southern end of the Bridger Range, and the western end of the Beartooth Range in east-central Gallatin County and west-central Park County, southwestern Montana (fig. 1).

The Gallatin Range is bounded on the east by Paradise Valley, through which the Yellowstone River flows. The Gallatin River valley delimits the west edge of the range.

The Livingston area includes part of the southwestern edge of the Crazy Mountains basin. This basin is elongated northwest and is approximately 40 to 75 miles wide and 100 to 130 miles long. The Crazy Mountains basin is bordered by the Beartooth Range to the south, the Gallatin Range to the southwest, the Bridger Range to the west, the Big Belt and Little Belt Mountains to the north, and the Lake Basin fault zone and Pryor uplift and related structures to the east (see pl. 3). The sedimentary deposits of Cretaceous and Paleocene age in the southwest part of the Crazy Mountains basin, chiefly in the area between Bozeman and Livingston, Mont., are the principal subject of this report.

ACKNOWLEDGMENTS

W. A. Cobban, C. L. Gazin, E. B. Leopold, R. H. Tschudy, and D. W. Taylor identified fossils collected in the area. A citation as to the type of fossils and other data appears with their identification. A. L. Benson, J. S. Hollingsworth, and C. A. Sandberg assisted in measuring stratigraphic sections. Mechanical analyses and heavy-mineral separates were made by R. F. Gantnier. Clay-mineral identifications were made by L. G. Schultz. The writer has benefited from discussions about stratigraphic problems or paleontologic interpretations with numerous colleagues and is particularly indebted to W. A. Cobban, J. R. Gill, W. R. Keefer, M. R. Klepper, W. J. Mapel, L. W. McGrew, W. J. McMannis, B. A. L. Skipp, and H. W. Smedes.

GEOLOGIC SETTING

The distribution of outcropping rock units in the Livingston area, as shown on plate 1, reflects a complex Cretaceous and early Tertiary history. The following "Stratigraphic Summary" and "Laramide Deformation" place the formations of this period into a historical framework for better understanding the depositional sequences and tectonic events.

STRATIGRAPHIC SUMMARY

The oldest rocks exposed in this area are Precambrian gneiss, granite, and schist in the cores of the major anticlines and in the uplifted blocks of the Beartooth, Bridger, and Gallatin Ranges. The overlying sedimentary rocks range in age from Middle Cambrian to Tertiary and are more than 20,000 feet thick (Roberts, 1964a–h). Only two systems, the Silurian and Triassic, are not represented. The Paleozoic rocks, more than 3,000 feet thick, are generally exposed along the axes of the major anticlines. Rocks of Jurassic age are 700 feet thick and form a prominent narrow belt along the flanks of anticlines. The stratigraphic sequence of the Jurassic and older formations is summarized on plate 2. Nearly 12,000 feet of Cretaceous rocks are also exposed along the flanks of anticlines, as well as in the troughs of intervening synclines. Lower Tertiary rocks include about 5,000 feet of Paleocene strata in the southwestern part of the Crazy Mountains basin and approximately 1,700 feet of volcanic and sedimentary rocks of Eocene age that cap ridges in the northern part of the Gallatin Range. A nearly complete cross section of the Paleozoic and Mesozoic formations is exposed in the eastern part of the area on walls of the lower canyon of the Yellowstone River just south of Livingston, Mont. (pl. 1).

Periodically, during Paleozoic and early Mesozoic time the Livingston area was part of a broad marine shelf that bordered the east side of the Cordilleran miogeosyncline, where predominantly carbonate rocks were deposited in shallow epicontinental seas. For approximately half of Paleozoic and early Mesozoic time, however, the area was above sea level and was subjected to subaerial erosion or was the site of deposition for thin layers of continental sedimentary rocks. For a résumé of the depositional and structural history of these rocks, the reader is referred to McMannis (1965).

In Late Jurassic time, the Ellis sea that had covered most of Montana withdrew northward into northern Canada. During the period of nonmarine deposition that followed, the Morrison Formation (Upper Jurassic) and Kootenai Formation (Lower Cretaceous) and their stratigraphic equivalents were deposited. Near the beginning of the late Albian of the Early Cretaceous, a northward transgressing Skull Creek (Thermopolis) sea covered most of Montana, and late in the Early Cretaceous a southward transgressing Mowry sea again covered most of Montana. During middle Albian through Campanian time, the western edge of the Cretaceous Interior basin of Montana was the site of several alternating westward transgressions and eastward regressions of the sea. Oscillations of the Cretaceous epicontinental sea that formed these stages probably

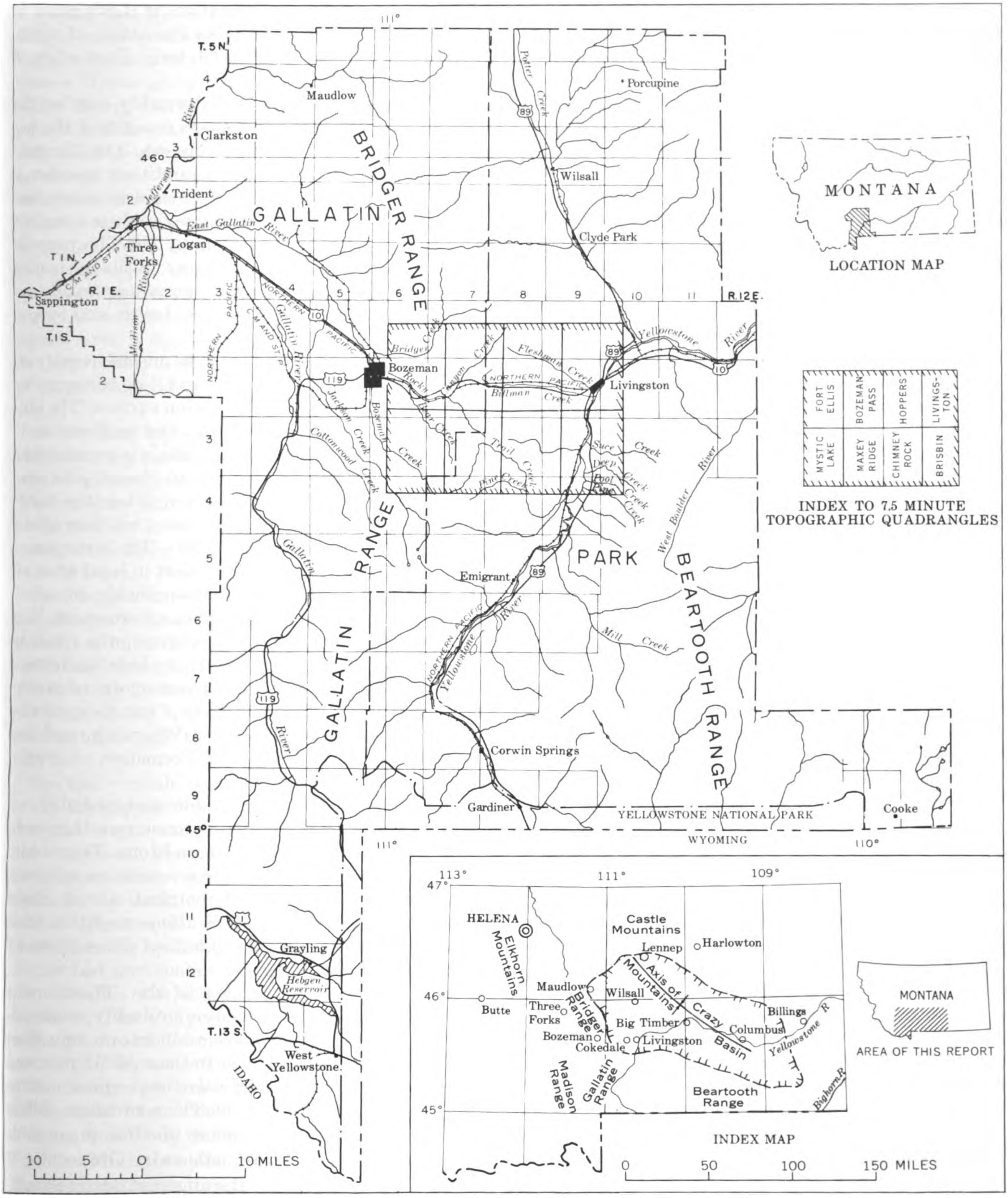


FIGURE 1.—Index maps, showing location of area discussed that is west of Livingston, Mont., and in Gallatin and Park Counties. Hachured line on lower inset map shows approximate limit of Crazy Mountains basin.

resulted from differential crustal movements. Regional studies of Upper Cretaceous shorelines by J. R. Gill and W. A. Cobban (oral commun., 1968) indicate that, while subsidence was taking place in one locality, uplift and erosion were taking place in another; thus transgression in one area was not necessarily accompanied by transgression in another. Rocks deposited during major Cretaceous regressions of the sea in southwestern Montana include the Frontier Formation, Eagle Sandstone, and parts of the Livingston Group and Fort Union Formation, or their stratigraphic equivalents. Prominent sandstone units, such as the lower and upper members of the Thermopolis Shale and the Eldridge Creek Member of the Cody Shale, represent near-shore marine deposition.

The Cretaceous System and Paleocene Series near Livingston, Mont., consist of sedimentary rocks that overlie the Morrison Formation of Late Jurassic age. These rocks were briefly described and correlated with Cretaceous and lower Tertiary rocks in other areas of Montana and Wyoming by Roberts (1965). This 17,715-foot-thick sequence includes the Kootenai Formation, Thermopolis Shale, Mowry Shale, Frontier Formation, Cody Shale, Telegraph Creek Formation, Eagle Sandstone, Cokedale Formation, Miner Creek Formation, Billman Creek Formation, Hoppers Formation, and the Fort Union Formation. Columnar sections illustrating the stratigraphic sequence of these formations are presented on plate 2. The correlation and stratigraphic relations of the Cretaceous rocks of the Livingston area, Montana, with other areas in Montana and Wyoming are shown in figure 2. The Paleocene Series consists of sedimentary rocks of the middle and upper parts of the Fort Union Formation.

Volcanism occurred intermittently throughout Cretaceous and early Tertiary time; volcanic ash or other volcanic detritus are major constituents of the Kootenai Formation, Mowry Shale, Livingston Group, Fort Union Formation, Cathedral Cliffs(?) Formation, and Golmeyer Creek and Hyalite Peak Volcanics. Volcanic ash, represented by bentonite, is also present in the Kootenai, Thermopolis, Mowry, Frontier, and Cody Formations and in the Livingston Group.

The Jurassic Period closed with uplift west of the Livingston area, probably near central or southeastern Idaho. Coarse clastic materials shed from this western upland were repeatedly reworked and formed a massive chert-pebble conglomerate that marks the beginning of Cretaceous deposition; this is the Pryor Conglomerate Member of the Kootenai Formation. During the remainder of Kootenai time, sandstone, limestone, and very fine grained clastic sediments accumulated on extensive alluvial plains and in a large fresh-water lake or lakes. The Kootenai Formation at Livingston is probably equivalent to the Lakota Formation of northeastern Wyoming and to the Cloverly Formation of central Wyoming (fig. 2).

The Thermopolis Shale unconformably overlies the Kootenai Formation and represents deposits of the initial transgression of the Cretaceous sea. The Thermopolis is subdivided into a lower sandstone member, a middle shale member, and an upper sandstone member. Exposures are generally poor; otherwise these members could be mapped as individual units. The Thermopolis Shale is dominantly soft, dark-gray to black, marine shale overlain and underlain by prominent sandstone ridges or ledges formed by the lower and upper members.

The lower sandstone member rests unconformably on the Kootenai Formation, commonly filling topographic depressions on the underlying erosion surface. The hiatus between the Kootenai Formation and the lower sandstone member of the Thermopolis Shale is presumed to be short inasmuch as the index fossil *Protelliptio douglassi* occurs immediately above and below the widespread disconformity separating the two formations (W. A. Cobban, oral commun., 1963). The lower member is a clean quartzose sandstone that in local areas of intense folding is a quartzite; it was probably deposited in a transgressive near-shore marine environment. The lower sandstone member of the Thermopolis Shale is approximately equivalent to the "Rusty beds" and Greybull Sandstone Member of the Thermopolis of north-central Wyoming, the Fall River Formation of the Black Hills area of northeastern Wyoming, and the Flood Member of the Blackleaf Formation of northwestern Montana (fig. 2).

The conformably overlying middle shale member is a black marine shale that contains numerous thin beds of siltstone and very fine grained sandstone. The middle shale member contains an excellent succession of plant microfossils similar to that of the Skull Creek Shale of north-central Wyoming. It is also correlative with the Taft Hill Member of the Blackleaf Formation of northwestern Montana (fig. 2).

The upper sandstone member of the Thermopolis overlies the middle shale member, probably conformably. It is a fine-grained arkosic sandstone unit that contains some interbedded shale in the middle part and represents deposition in a regressive near-shore marine and brackish-water environment. This sandstone differs from the lower sandstone member in that it contains feldspar and abundant heavy minerals. Glauconite is present in the upper part of the upper sandstone member. The upper sandstone member is probably equivalent to the Muddy Sandstone Member of north-central

Wyoming and the Newcastle Sandstone of the Black Hills area of northeastern Wyoming and part of the Vaughn Member of the Blackleaf Formation in northwestern Montana (fig. 2).

The Mowry Shale conformably overlies the Thermopolis Shale. It consists of dark-gray to brownish-gray shale and mudstone interbedded with siltstone and sandstone. Near Bozeman the Mowry is very carbonaceous and contains plant fragments and thin streaks of coal, which suggests relatively quiet brackish-water deposition. Near Livingston the Mowry is micaceous and pyritic and commonly glauconitic; it contains spores and pollen which suggest deposition in a shallow restricted marine environment. The Mowry in the Livingston area is equivalent to the Mowry of Wyoming and is probably equivalent to the Bootlegger Member of the Blackleaf Formation in northwestern Montana (fig. 2).

At the base of the Upper Cretaceous are massive ridge-forming sandstones of the Frontier Formation—which overlies the Mowry Shale, probably conformably. The boundary between the two formations is at the base of the Boulder River Sandstone Member. All the sandstones of the Frontier contain abundant heavy minerals and dark-gray chert, which give them a "salt-and-pepper" appearance. Sedimentary features and faunal assemblages indicate that the sediments of the Frontier Formation in the Livingston area were deposited in an oscillating regressing sea that was shallow and brackish. The Frontier Formation at Livingston has not been precisely dated, but spores and pollen suggest that it approximately spans the lower half of the Cenomanian (fig. 2).

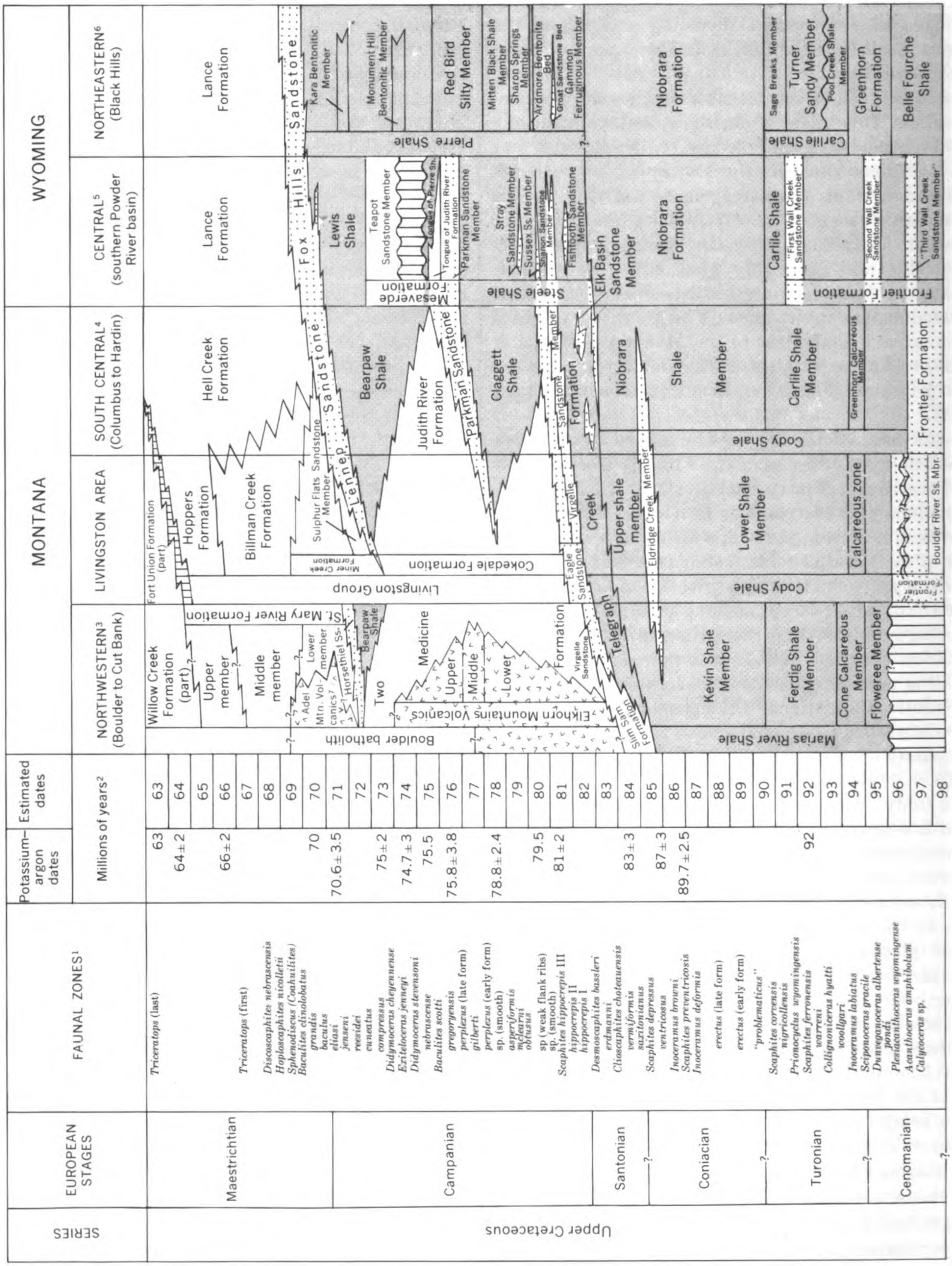
The Cody Shale conformably overlies the Frontier in the Livingston area and represents a transgressive return to deeper water marine conditions with the shoreline to the west. The Cody Shale consists of dark-gray to dark-brown shale interbedded with siltstone and sandstone. In the middle of the Cody is a persistent thin-bedded glauconitic sandstone, named the Eldridge Creek Member by Roberts (1964c). This is an excellent marker bed and contains a shallow-water marine fauna that includes the short-ranging ammonite *Scaphites depressus*. The Cody Shale at Livingston is equivalent to the Niobrara Formation, Carlile Shale, and upper part of the Frontier Formation of central Wyoming.

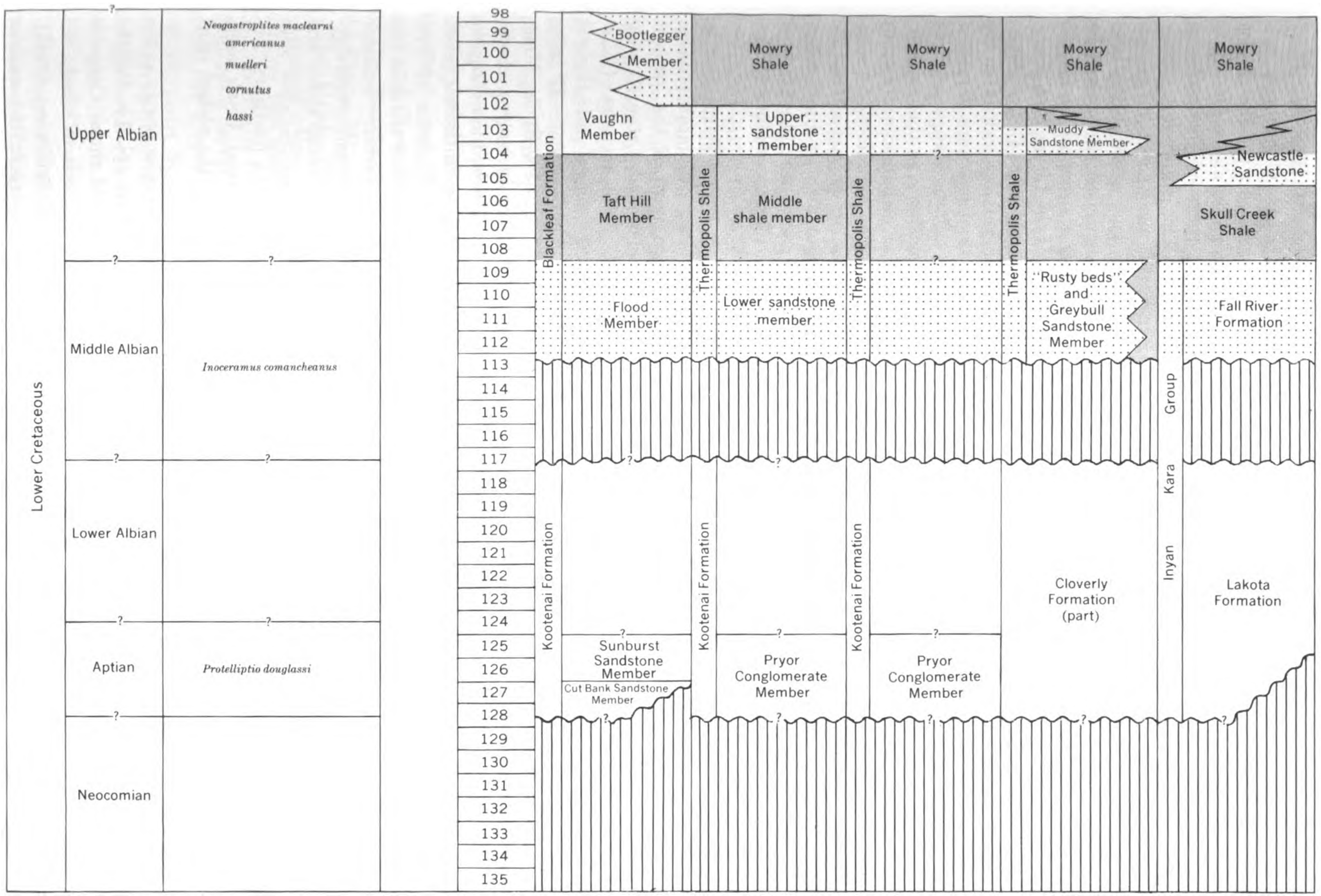
The Telegraph Creek Formation is a shallow-water marine unit transitional between the underlying offshore marine Cody Shale and the overlying near-shore Virgelle Sandstone Member of the Eagle Sandstone. The gradual transition in sedimentation in this area reflects the gradual uplift of the Elkhorn Mountains and other structural units to the west and an eastward movement of the Cretaceous strandline. The Telegraph Creek Formation consists of thin beds of sandy siltstone and sandstone. Weed (1893, p. 16) referred to this part of the stratigraphic section at Cokedale as the "Tombstone sandstones." The Telegraph Creek Formation in this area very gradually changes in texture upward from the very fine grained upper shale member of the Cody Shale to the fine- to medium-grained Eagle Sandstone.

The Eagle Sandstone conformably overlies the Telegraph Creek Formation in the area west of Livingston and consists of sandstone with intercalated beds of coal and carbonaceous siltstone. These strata represent lagoonal, estuarine, deltaic, and swamp deposits laid down near ancient shorelines. The coal beds are commonly lenticular, but the zones in which they occur are laterally persistent. Some of the coal is commercial, and estimated reserves of more than 300 million tons are present (Roberts, 1966, p. A49–A51). A massive persistent quartzose sandstone at the base is called the Virgelle Sandstone Member. Locally, the uppermost beds of the Virgelle contain 1 percent or more magnetite concentrated in a regressive beach deposit.

Late in the Coniacian or early Santonian Stage of Late Cretaceous time, epeirogenic arching began in western Montana, and the Eagle sea regressed to the east. This period of orogeny and erosion was accompanied by volcanism, which formed the thick Elkhorn Mountains volcanic pile (Klepper and others, 1957, p. 31–41).

After withdrawal of the Late Cretaceous Eagle sea in western Montana, the area east of the Bridger Range and north of the Beartooth Range was gradually warped downward and formed the Crazy Mountains basin. This structural feature is elongated northwest and is approximately 40 to 75 miles wide and 100 to 130 miles long. The basin is asymmetrical, and more than 13,000 feet of sediment was deposited in its deeper (western) part during Late Cretaceous and Paleocene time (Roberts, 1963, p. B86). The sediment was derived predominantly from andesitic volcanic rock of the Elkhorn Mountains volcanic pile. The stratigraphic sequence for this part of the basin indicates that deposition was continuous and that the rocks grade laterally to the east and northeast into finer grained marine and nonmarine beds. The continental section near Livingston, Mont., is subdivided into the Livingston Group, which includes four formations of Late Cretaceous age, and the Fort Union Formation of Late Cretaceous and Paleocene age (Roberts, 1963). Formations of the Livingston Group are thick alternating series of coarse- and fine-grained rocks that are characterized by rapid vertical and lateral variations commensurate with pulses of the Laramide orogeny. These rocks probably were


SERIES
Upper Cretaceous
EUROPEAN STAGES
Maestrichtian
Campanian
Santonian
Coniacian
Turonian
Cenomanian
FAUNAL ZONES[1]
Triceratops (last)
Triceratops (first)
Discoscaphites nebrascensis
Hoploscaphites nicolleti
Sphenodiscus (Coahuilites)
Baculites clinolobatus
grandis
baculus
eliasi
jenseni
reesidei
cuneatus
compressus
Didymoceras cheyennense
Exiteloceras jenneyi
Didymoceras stevensoni
nebrascense
Baculites scotti
gregoryensis
perplexus (late form)
gilberti
perplexus (early form)
sp. (smooth)
asperiformis
mclearni
obtusus
sp (weak flank ribs)
sp. (smooth)
Scaphites hippocrepis III
hippocrepis II
hippocrepis I
Desmoscaphites bassleri
erdmanni
Clioscaphites choteauensis
vermiformis
saxitonianus
Scaphites depressus
ventricosus
Inoceramus browni
Scaphites preventricosis
Inoceramus deformis
erectus (late form)
erectus (early form)
"problematicus"
Scaphites corvensis
nigricollensis
Prionocyclus wyomingensis
Scaphites ferronensis
warreni
Collignoniceras hyatti
woollgari
Inoceramus labiatus
Sciponoceras gracile
Dunveganoceras albertense
pondi
Plesiacanthoceras wyomingense
Acanthoceras amphibolum
Calycoceras sp.
Potassium-argon dates
Millions of years[2]
63
64±2
66±2
70
70.6±3.5
75±2
74.7±3
75.5
75.8±3.8
78.8±2.4
79.5
81±2
83±3
87±3
89.7±2.5
92
Estimated dates
63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98
MONTANA
NORTHWESTERN[3] (Boulder to Cut Bank)
Willow Creek Formation (part)
Upper member
Middle member
Lower member
St. Mary River Formation
Adel Mtn. Volcanics?
Horsethief Ss.
Bearpaw Shale
Two Medicine Formation
Upper
Middle
Lower
Elkhorn Mountains Volcanics
Boulder batholith
Virgelle Sandstone
Telegraph
Slim Sam Formation
Kevin Shale Member
Ferdig Shale Member
Cone Calcareous Member
Floweree Member
Marias River Shale
LIVINGSTON AREA
Fort Union Formation (part)
Hoppers Formation
Billman Creek Formation
Sulphur Flats Sandstone Member
Miner Creek Formation
Livingston Group
Cokedale Formation
Lennep
Virgelle
Eagle Sandstone
Creek
Upper shale member
Eldridge Creek Member
Lower Shale Member
Calcareous zone
Cody Shale
Frontier Formation
Boulder River Ss. Mbr.
SOUTH CENTRAL[4] (Columbus to Hardin)
Hell Creek Formation
Sandstone
Bearpaw Shale
Judith River Formation
Parkman Sandstone
Claggett Shale
Sandstone Member
Formation
Niobrara
Shale
Member
Cody Shale
Carlile Shale Member
Greenhorn Calcareous Member
Frontier Formation
WYOMING
CENTRAL[5] (southern Powder River basin)
Lance Formation
Fox Hills
Lewis Shale
Teapot Sandstone Member
Tongue of Pierre Sh.
Mesaverde Formation
Tongue of Judith River Formation
Parkman Sandstone Member
Stray Sandstone Member
Sussex Ss. Member
Shannon Sandstone Member
Fishtooth Sandstone Member
Steele Shale
Elk Basin Sandstone Member
Niobrara Formation
Carlile Shale
"First Wall Creek Sandstone Member"
"Second Wall Creek Sandstone Member"
"Third Wall Creek Sandstone Member"
Frontier Formation
NORTHEASTERN[6] (Black Hills)
Lance Formation
Sandstone
Kara Bentonitic Member
Monument Hill Bentonitic Member
Red Bird Silty Member
Mitten Black Shale Member
Sharon Springs Member
Ardmore Bentonite Bed
Groat Sandstone Bed
Gammon Ferruginous Member
Pierre Shale
Niobrara Formation
Sage Breaks Member
Turner Sandy Member
Pool Creek Shale Member
Carlile Shale
Greenhorn Formation
Belle Fourche Shale



[1] Modified from Cobban (1958); Zapp and Cobban (1960); Cobban (1962a, 1962b).

[2] Modified from Gill and Cobban (1966); Tilling, Klepper, and Obradovich (1968); Robinson, Klepper, and Obradovich (1969).

[3] Modified from Klepper, Weeks, and Ruppel (1957); Cobban and others (1959); Schmidt and Zubovic (1961); W. A. Cobban (oral commun., 1962); M. R. Klepper (oral commun., 1962, 1969); R. G. Schmidt (oral commun., 1964); Viele and Harris (1965).

[4] Modified from Hancock (1918); Richards (1955).

[5] Modified from Cobban (1958); J. R. Gill (oral commun., 1962); Gill and Cobban (1966); Horn (1959); Eicher (1960).

[6] Modified from Cobban (1958); Robinson, Mapel, and Cobban (1959); Gill and Cobban (1961, 1962); Knechtel and Patterson (1962); Robinson, Mapel, and Bergendahl (1964).

[7] Lyons, (1944).

EXPLANATION

Predominantly offshore marine

Predominantly near-shore marine and brackish water

Predominantly nonmarine

Predominantly volcanic rock

FIGURE 2.—Correlation and stratigraphic relations of Cretaceous rocks of the Livingston area, Montana, with other areas in Montana and Wyoming.

deposited in fluvial channel systems or on associated extensive flood plains, near sea level, judging by their similarities to Holocene deposits found in such environments. The Livingston Group has been subdivided, in ascending order, into the Cokedale, Miner Creek, Billman Creek, and Hoppers Formations.

The Cokedale Formation is a nonmarine unit composed of siltstone and sandstone, and lesser amounts of mudstone, tuff, bentonite, and coal in the lower part; it correlates eastward with the Claggett Shale, the Judith River Formation, and Bearpaw Shale and in northwestern Montana with the Two Medicine Formation (fig. 2). The Cokedale rests conformably on the Eagle Sandstone at the type section at Cokedale, Mont. The Miner Creek Formation conformably overlies the Cokedale Formation and consists largely of alternating beds of nonmarine siltstone and sandstone—including a prominent ridge-forming unit, the Sulphur Flats Sandstone Member, at the base. The Miner Creek correlates eastward with the lower part of the Hell Creek Formation, and the Sulphur Flats Sandstone Member is the nonmarine facies of the marine Lennep Sandstone and Horsethief Sandstone (fig. 2). The Billman Creek Formation is a nonmarine sequence of red, purple, and green mudstone, tuff, and bentonite, including a few intercalated beds of sandstone; it correlates northward and eastward with the middle part of the Hell Creek Formation (fig. 2). The Billman Creek rests conformably on the Miner Creek Formation at the type section on Billman Creek, near Cokedale, Mont. The type Hoppers Formation, also nonmarine, is mostly sandstone and conglomerate interbedded with some siltstone, mudstone, and tuff; it correlates northward and eastward with the upper part of the Hell Creek Formation (fig. 2).

The Livingston Group at Cokedale, Mont., is overlain by nonmarine sandstone and conglomerate that alternate with siltstone and mudstone; this sequence is assigned to the Fort Union Formation (Roberts, 1963, p. B89). The Fort Union includes three lithologic units: a lower conglomeratic sandstone member, a middle member of sandstone and mudstone, and an upper conglomeratic sandstone member; the top is everywhere an erosion surface. The lower member is assigned a Late Cretaceous age because of plant microfossils, stratigraphic position, and degree of erosion in source areas as implied by constituent rock types.

During deposition of the Fort Union Formation near Livingston, streams from the west dropped their sediment and created alluvial fans, channel-fill sands, deltas, and flood-plain deposits. The character of the rocks at the base of the Fort Union differs markedly from that of rocks of the underlying Livingston Group. The conglomerates in the Livingston Group are composed almost entirely of Cretaceous volcanic rock, whereas the conglomerates in the Fort Union contain mostly igneous, metamorphic, and sedimentary rock fragments derived from rocks of Precambrian, Paleozoic, and Mesozoic age. This significant change in provenance and an increased size of rock fragments suggest a closer source area and greater depth of erosion in the source area during deposition of the Fort Union Formation than during the deposition of the Livingston Group. Deposition of the Livingston Group was not restricted at the beginning to the Crazy Mountains basin. Sediments similar and equivalent to the Cokedale and Miner Creek Formations were deposited in the southern part of the Gallatin Range and the northwest corner of Yellowstone Park, in the southern part of the Madison Range, in areas immediately south of the Elkhorn Mountains, and at Maudlow. At some time during the deposition of the upper part of the Livingston Group, or Hell Creek equivalent, sedimentation ceased to the west and south; and near the close of deposition of the Livingston Group, sedimentation ceased to the north.

During deposition of the Fort Union Formation in the southwestern part of the Crazy Mountains basin, the borderland in the northern part of the present Gallatin Range was elevated and eroded. Later, in early Eocene time, the northern part of this ancestral Gallatin Range was covered by volcanic or volcanic-derived sedimentary rocks. At their northern extent—15 miles southwest of Livingston, near Chimney Rock, Mont. (Roberts, 1964e)—these are primarily coarse clastic rocks, flows, flow breccias, and mudflows, including the Crandall(?) Conglomerate at the base of the sequence. This boulder conglomerate consists of clasts of Precambrian igneous and metamorphic rock, Paleozoic and Mesozoic sedimentary rock, and lower Tertiary volcanic rock. Plant microfossils from a local carbonaceous claystone near the base of this sequence, stratigraphic and structural relations, and lithologic similarities with stratigraphic units of known age in the northern Absaroka Range and Yellowstone National Park area, Wyoming, indicate a correlation with the oldest units of the Eocene.

Post-Eocene bolson and fluvial deposits occur at the western edge of the area of this report (pl. 1). For the depositional and structural history of these Cenozoic rocks, the reader is referred to Hackett, Visher, McMurtrey, and Steinhilber (1960) and Robinson (1961). Glacial and other Pleistocene deposits at the eastern edge of this report are discussed by Horberg (1940).

LARAMIDE DEFORMATION

The interval of time for the Laramide orogeny varies geographically in the Rocky Mountain region. Therefore, locally one must identify the interval of mountain building and basin development assigned to the Laramide. In the Livingston area, volcanic pebbles in the Virgelle Sandstone Member of the Eagle Sandstone suggest a beginning of uplift to the west in early Eagle time. However, a flood of volcanic debris in the basal part of the overlying Livingston Group indicates that the first major tectonic pulse that began Laramide deformation took place in the Livingston area at the end of Eagle time. The final uplift of the Laramide orogeny in the Livingston area is of early Eocene age. North of Livingston this uplift was accompanied by major intrusions in the Castle, Crazy, and Little Belt Mountains; south of Livingston this uplift produced the Crandall(?) Conglomerate. Thus, for the purposes of this report, the term Laramide refers only to those tectonic events transpired from the beginning of deposition of the Livingston Group (late Santonian Stage of Late Cretaceous time) to the close of deposition of the Crandall(?) Conglomerate (early Eocene Epoch of early Tertiary time). The structural pattern established during the Laramide deformation was subsequently modified by normal faulting and volcanism.

Epeirogenic arching in the vicinity of the Elkhorn Mountains, near Boulder, Mont., late in the Coniacian or early Santonian Stage of Late Cretaceous time (fig. 2) was accompanied by erosion and truncation of beds as old as the Lodgepole Limestone of Early Mississippian age. This episode of uplift and erosion was followed by the volcanism which created the thick Elkhorn Mountains volcanic pile (Klepper and others, 1957). Contemporaneous with this period of orogeny, the Eagle sea gradually withdrew from western Montana and the area east of the Bridger Range and north of the Beartooth Range gradually subsided to form the Crazy Mountains basin (pl. 3).

The Crazy Mountains basin is bounded by major Laramide structures: the Beartooth and Bridger uplifts on the south and west; the Little Belt and Big Belt uplifts on the north and northwest; the Lake Basin fault zone on the northeast; and the Nye-Bowler lineament, the Pryor uplift, and a narrow connection with the Bighorn Basin on the southeast (pl. 3). Also, stratigraphic information from drilling suggests that a slight arch connects the Pryor and Little Belt uplifts and provides additional definition to the northeast side of the basin.

Although the Crazy Mountains basin formed during the period of Laramide basin development, its geometry was probably influenced by Precambrian structural and sedimentary elements. Along the northeastern edge of the basin is the Lake Basin fault zone or Lake Basin lineament and along the southeastern edge is the Nye-Bowler lineament. These Laramide features that border the basin probably represent reactivated Precambrian wrench faults or fault zones at depth. The Nye-Bowler lineament, mapped and described by Wilson (1936), is a compound feature that includes folds, en echelon faults, and a few small volcanic centers which extend from the Pryor Mountains northwestward parallel to the Beartooth uplift (pl. 3). The en echelon folds between Livingston and Bozeman may be a western extension of the Nye-Bowler lineament. The surface en echelon faults trend northeast, which suggests left-lateral movement. Wilson (1936, p. 1182) concluded that these faults were produced near the surface by lateral movement along a buried fault plane in the basement complex. A similar origin had previously been proposed by Chamberlin (1919) for en echelon faults of the Lake Basin fault zone (pl. 3). Osterwald (1961) and Smith (1965) summarized the earlier work of Chamberlain and Wilson and extended these lineaments regionally as transcurrent fault zones.

Battle Ridge, a prominent northeast-trending topographic feature in the western part of the Crazy Mountains basin (pl. 3) is also probably a surface expression of a reactivated Precambrian fault at depth. This structural element, projected northeastward, divides the Crazy Mountains basin in two dissimilar parts. In the northern part, the basin is underlain by a thick sequence of sedimentary rock, the LaHood Formation of the Belt Supergroup of late Precambrian age, whereas in the southern part these rocks are absent. McMannis (1963, p. 415) reported 10,250 feet of LaHood Formation north of the Pass fault in the Bridger Range, and his generalized isopach map (1963, p. 412) suggests thicknesses for the Belt deposits that range from 0 to 15,000 feet in the northern part of the Crazy Mountains basin. The presence of this thick wedge of Belt Supergroup must have influenced the structural response of the younger rock units to regional stresses. Paralleling the Battle Ridge element to the south are the Emigrant fault and related structures (pl. 3). Extension or projection of this structural element to the north-northeast, approximately to the intersection of the Shawmut and Big Coulee-Hailstone structures, suggests structural control similar to that of the Battle Ridge element. Appalachian or symmetrical folding is characteristic of the northern part of the Crazy Mountains basin, and asymmetrical folding and en echelon fold axes are characteristic of the southern part. Also, in the northern part of the basin most of the intrusive rocks are alkalic, and in the southern part most are calc-alkalic. A fourth significant difference is that in the southern part there are numerous calcite dikes—some of optical quality (Stoll and Armstrong, 1958)—whereas none are reported in the northern part (pl. 3).

The Bridger Range on the west edge of the Crazy Mountains basin is the result of a complex uplift and basinward (eastward) thrusting, and the Beartooth Range on the southwest edge is the result of a complex uplift and basinward (northeastward) thrusting. For a detailed study of the structural geology of the Bridger Range, the reader is referred to McMannis (1955) and, for the Beartooth Range, to Foose, Wise, and Garbarini (1961). These uplifts developed slowly during deposition of the Livingston Group and Fort Union Formation, and the thrusting occurred after deposition of the Fort Union. Lateral forces that produced the thrusting were accompanied by a lesser opposing force from within the basin, and as the Bridger and Beartooth uplifts evolved, these structural elements were forced basinward. In the area between Bozeman and Livingston, arcuate northwest-trending en echelon folds formed, each convex toward the southwest and parallel to the axis of the Crazy Mountains basin (pls. 1, 3). In the Livingston area, folding that accompanied thrusting produced asymmetric anticlines that had the steeper dips on the southwest flanks. The Canyon Mountain anticline grew until it became recumbent on its southwest flank (Roberts, 1964 a, b). The Canyon Mountain anticline is related to the complex Beartooth uplift and represents essentially a pivot at the Beartooth uplift's west end with basinward movement increasing to the east.

Subsidence and deposition were greater in the western part (west of the Emigrant fault trend) of the Crazy Mountains basin than in the eastern part; both were greatest in late Campanian and Maestrichtian time. The asymmetric subsidence of the basin may have been related to rock transfer at depth and to the consequent extrusion of the Elkhorn Mountains Volcanics and the intrusion of the Boulder batholith in nearby areas to the west; however, an asymmetric configuration seems common to most Laramide intermontane basins of Montana, Wyoming, and Colorado (Prucha and others, 1965, p. 975). Deposition was continuous during latest Cretaceous and Paleocene time in the deepest part of the basin, where more than 13,000 feet of sediments, derived predominantly from volanic rock, was deposited. The physical similarities of rocks of the Livingston Group and Fort Union Formation suggest that deposition in the western part of the basin took place near sea level and that the rate of sedimentation closely balanced the rate of subsidence.

Extensive erosion accompanied the uplift, and by Late Cretaceous time parts of the Bridger and Beartooth uplifts were truncated to expose Precambrian rocks (as shown by the basal conglomerate of the Fort Union Formation, which in the Livingston area contains rock fragments derived from Precambrian, Paleozoic, and Mesozoic rocks).

During folding, lateral movement of thick competent sandstone beds, such as in the Eagle Sandstone, caused local folding and shearing of the intervening incompetent finer grained clastic beds. Squeezing that accompanied this movement produced lenticular beds, and in local areas of intense folding, bedding-plane faults developed under shear. Where lateral compressional forces were most severe, failure of the folds occurred and large thrust or high-angle reverse faults developed (fig. 3).

Most thrusts in the Bridger Range initially dipped west and those in the Beartooth Range generally dipped southwest. Basinward dips are present locally and are the result of subsequent folding. In the area west of Livingston, thrust faults developed in an en echelon arrangement paralleling the folds. Field relations of the Livingston faults suggest that the direction of compressive force was toward the southwest and that initial dips of the faults were to the north. Individual thrust faults, in this area, commonly vary from low-angle thrust faults to high-angle reverse faults. Similar structural features also occur along the perimeter of the Bighorn Basin (Chamberlin, 1940) and the Wind River Basin (Keefer, 1970).

Folding and thrusting continued during post-Fort Union and pre-Wasatch time in the Livingston area, but with less magnitude than during Fort Union time. Earlier thrust plates, such as those on the south flank of the Canyon Mountain anticline, were folded during this post-Fort Union and pre-Wasatch time, locally changing the dip to a basinward direction. Thrust faults with an initial basinward (north) dip then developed on the north flank of the Canyon Mountain anticline. On the southwest flank of the Canyon Mountain anticline a complex arrangement of thrust faults separated by zones of oxidized sedimentary rocks suggests several pulses of thrusting with intervening periods of weathering and erosion (Roberts, 1964 a, b).

During deposition of the Fort Union Formation in the southwestern part of the Crazy Mountains basin, the borderland in the northern part of the Gallatin Range and the Bridger Range continued to rise and restricted the western limit of the Fort Union of Montana to this basin. The Fort Union and older rocks were folded, probably near the close of the Paleocene or

Figure 3.—View northwest of the exposed Precambrian core of the recumbent Canyon Mountain anticline with the Suce Creek thrust fault along its base. Photograph taken from the center of the NE¼ sec. 27, T. 3 S., R. 9 E. Geology shown on plate 1 or in Roberts (1964a). p€g, Precambrian rocks; €f, Flathead Quartzite; €w, Wolsey Shale; €m, Meagher Limestone; €ps, Park Shale; €p, Pilgrim Limestone; €gs, Grove Creek and Snowy Range Formations; Ob, Bighorn Dolomite; Dj, Jefferson Dolomite; Mm, Madison Group; Pa, Amsden Formation; Kk, Kootenai Formation; Kmt, Mowry and Thermopolis Shales.

beginning of the Eocene. South of the Canyon Mountain anticline, which formed the southwestern barrier of the basin, the ancestral Gallatins continued to be eroded, and no Fort Union sediments have been reported in this area. In early Eocene time the area of the Gallatin Range was covered by sedimentary and volcanic rocks, none of which extended north of the Canyon Mountain anticline. These Eocene deposits remain relatively undeformed in contrast to the underlying folded formations (Roberts, 1964e), which indicates that the last major period of folding for this area occurred near the end of Paleocene or the beginning of Eocene time. This conclusion was also reached by W. J. McMannis (written commun., 1962) in the Garnet Mountain area south of Bozeman, Mont. He observed a carbonaceous siltstone of Wasatchian provincial age at five separate localities, which do not differ in elevation by more than 800 feet. McMannis attributes the differences in elevation to post-volcanic (Wasatchian) tilting and warping related to post-Laramide normal faults bordering the Gallatin Range and to initial differences in elevation on the pre-volcanic erosion surface.

In post-Paleocene time, after the folding and thrust faulting, rocks in the Livingston area were intruded by a few dikes and sills of diorite. These intrusions generally occur along tension fractures or faults that are parallel to fold axes (fig. 4). Northeast of the Livingston area, laccoliths, stocks, sills, and several generations of dikes were also intruded at this time (pl. 3) along the axis of the Crazy Mountains basin (Wolff, 1938, p. 1625), along tension and shear joints produced during the syclinal folding. Wolff (1938) described an older

FIGURE 4.—Andesitic dikes cutting mudstones and sandstones of the Billman Creek Formation in the NE¼ sec. 13, T. 2 S., R. 8 E. The dikes have intruded along parallel tension fractures without offsetting parts of the lower massive sandstone. The dike left of the center of the photograph did not penetrate the upper massive sandstone.

calcalkalic series, chiefly in the south-central part of the Crazy Mountains basin, and a younger alkalic series, found chiefly in the north-central part of the basin. Uplift and erosion have now bared these igneous bodies which form the Crazy Mountains.

Post-Laramide epeirogenic uplift, near the close of the Tertiary, raised the Crazy Mountains basin and adjacent areas about 5,000 feet above their previous elevations. Large-scale faulting has also characterized the latest tectonic activity in the area and may have accompanied the regional uplift. The dominant movement was nearly vertical on normal faults. Displacement along these faults ranges from a few feet to the more than 5,000 feet on the Emigrant fault (Horberg, 1940). The faults of small displacement are generally parallel to fold axes and are most abundant near the crests of anticlines (pls. 1, 3), whereas the faults of large displacement, such as the Emigrant fault, trend north-northeast. The association of the smaller normal faults with the folds indicates that they are older than the larger faults. The Emigrant fault may have been active since Late Cretaceous time, as its northeast trend parallels other structural elements of this age. Evidence in the adjacent Gallatin Range that the Emigrant fault was active in Eocene time includes the greater tilting of Eocene volcanic rocks that are low stratigraphically in the Hyalite Peak Volcanics, compared with the tilting of those higher in the sequence (R. A. Chadwick, written commun., 1969). Horberg (1940, p. 293) presented evidence that the Emigrant fault was intermittently active from Miocene to Holocene time.

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

The Lower Cretaceous Series in the area west of Livingston consists of the Kootenai Formation, Thermopolis Shale, and Mowry Shale. The series is 1,250 feet thick and consists of continental clastic and carbonate rocks in the Kootenai Formation and marine shale and mudstone interbedded with quartzose sandstone in the Thermopolis and Mowry Shales.

KOOTENAI FORMATION

The Kootenai Formation is a nonmarine sequence of conglomerate, sandstone, siltstone, claystone, mudstone, limestone, and tuff of Early Cretaceous age (fig. 2) that unconformably overlies the Morrison Formation (Jurassic). The Kootenai may be divided into two units: (1) a basal massive crossbedded conglomerate, conglomeratic sandstone, and coarse-grained sandstone called the Pryor Conglomerate Member, and (2) an unnamed sequence of variegated siltstone, claystone, mudstone, limestone, and tuff interbedded with calcareous sandstone. The Kootenai Formation is 245 to 295 feet thick, including the basal 24- to 37-foot Pryor Conglomerate Member, and is unconformably overlain by the lower sandstone member of the Thermopolis Shale at its reference section. A reference section of the Kootenai is shown in figure 5 and is described in measured section 1.

Lower Cretaceous rocks of the Kootenai Formation in the area west of Livingston were first mapped by Iddings and Weed (1894) as the Dakota Sandstone. Calvert (1912a, p. 31) later correlated the sequence with the Kootenai Formation as established near Great Falls, Mont., by Fisher (1908, p. 78–80; 1909, p. 30). Fisher (1908, p. 93) pointed out that the Kootenai near Great Falls extended southward through Montana into the southern part of the Bighorn Basin, Wyoming, where equivalents were called the Cloverly Formation. The correlation was later extended southward to Colorado Springs, Colo., by Lee (1927, p. 26) who established that equivalents of the Cloverly were part of the Dakota Group of Colorado.

A comprehensive review of the conglomerate of the Cloverly Formation and its equivalents was made by Lammers (1939, p. 113). He suggested an unconformity (1939, p. 118) at the base of the Cloverly conglomerate or its equivalents and assigned coal-bearing rocks beneath the conglomerate to the Upper Jurassic. The unconformity was later confirmed and described by Cobban (1945, p. 1270, 1281), and nonmarine rocks beneath the unconformity were assigned to the Morrison Formation. The unconformity described by Cobban (1945, p. 1270) near Great Falls, Mont., is correlative with the unconformity at the base of the Kootenai at Livingston, Mont.

The basal conglomerate, conglomeratic sandstone, and sandstone are referred to as the Pryor Conglomerate Member of the Cloverly Formation in north-central Wyoming (Hares, 1917, p. 429; Bowen, 1918, pl. 25) and the Pryor Conglomerate Member of the Kootenai Formation in southwestern Montana (Roberts, 1965,

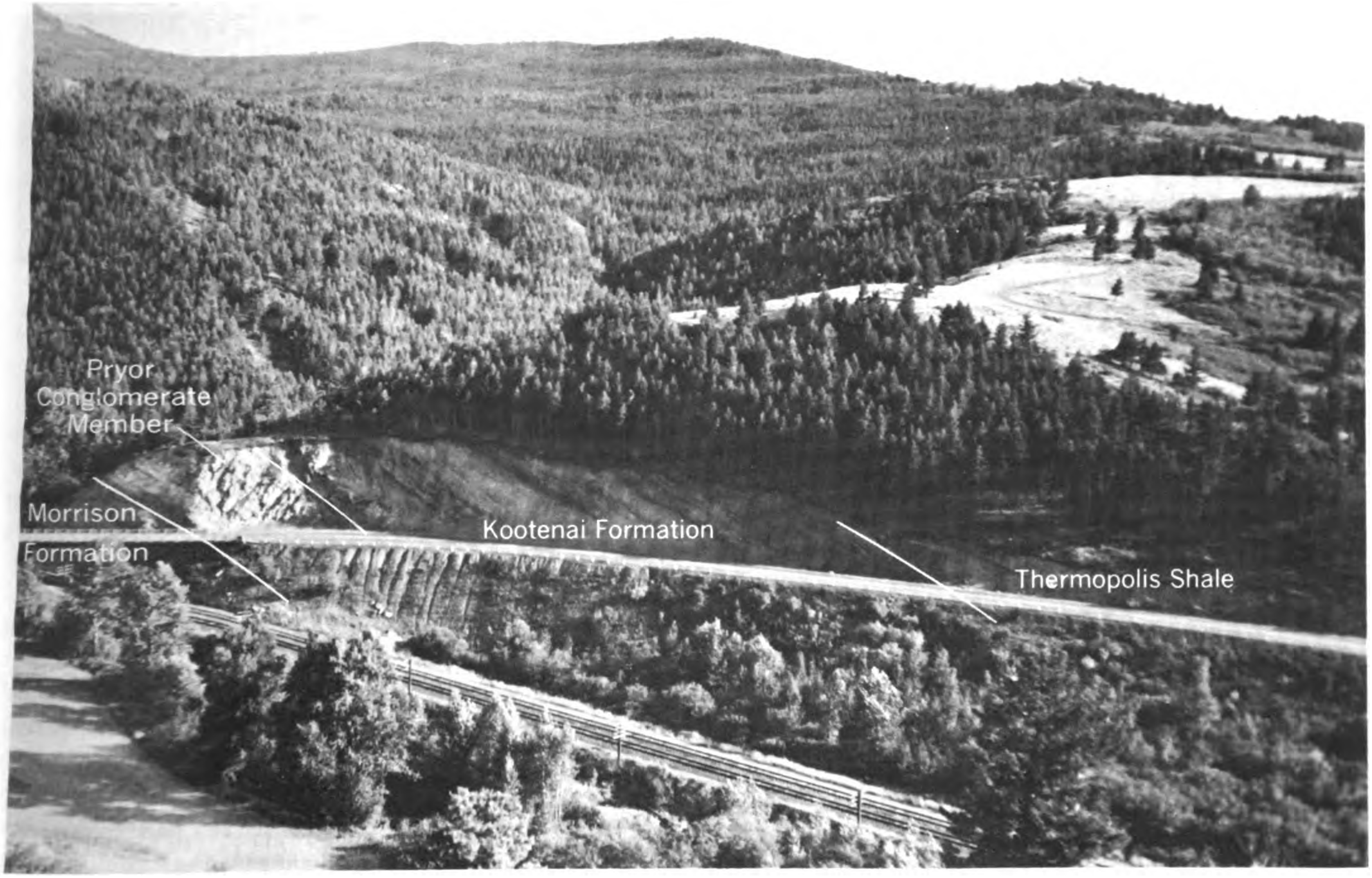


FIGURE 5.—Reference section of Kootenai Formation on the west flank of Chestnut Mountain anticline in the NE¼ sec. 25, T. 2 S., R. 6 E. (measured section 1). View is south; west end of Rocky Canyon at the left edge of the photograph.

p. B55). Equivalent beds elsewhere in Montana include: the Cut Bank and Sunburst Sandstone Members of the Kootenai Formation on the northwest flank of the Sweetgrass arch area of northwestern Montana, the Sunburst Sandstone Member in the subsurface over much of the Sweetgrass arch (Cobban, 1955, p. 107), the Third Cat Creek Sand of central Montana (Reeves, 1927, p. 48; 1931, p. 139), and the Lakota Formation of southeastern Montana and northeastern Wyoming (Darton, 1901; Rubey, 1931; Waagé, 1959; and Post and Bell, 1961).

The Pryor Conglomerate Member is not exposed between the type section in the Pryor Mountains and Nye, Mont. (about 35 miles west of Red Lodge, Mont.). It is either buried by younger deposits or cut out by faulting. Gardner, Hendricks, Hadley, and Rodgers (1945) extended the Pryor across this area in the subsurface. The Pryor crops out as a persistent ridge along the north flank of the Beartooth Range from Nye to Livingston. South of Livingston along the north end of the Gallatin Range the basal conglomeratic sandstone of the Kootenai forms prominent cuestas and hogback ridges. The overlying fine-grained clastic rocks and limestones are poorly exposed and generally form red clay soil-covered slopes and valleys.

LITHOLOGIC COMPOSITION

The lower lithologic unit, the Pryor Conglomerate Member of the Kootenai Formation, is a persistent massive ridge-forming unit of conglomerate, conglomeratic sandstone, and sandstone. At stratigraphic section 1 on the west flank of the Chestnut Mountain anticline, the Pryor is 37 feet thick and is crossbedded, well indurated, poorly sorted, and has scour-and-fill structures. The lower part of the unit is conglomerate or conglomeratic, and the upper part is sandstone. The coarser fragments are mostly subrounded to rounded pebbles in a matrix of poorly sorted sand grains. The pebbles are generally less than 1 inch in diameter but may be as much as 2 inches. The pebbles are dominantly gray or black chert, and a few are quartzite and limestone; they resemble rocks from the Madison Group and the Amsden, Quadrant, and Phosphoria Formations. Pebbles are commonly concentrated on some of the cross-stratification surfaces. Along the southern flank of Canyon Mountain, about 12 miles southwest of Livingston, the Pryor Conglomerate Member contains repeated reverse graded bedding (fig. 6). The sandstone is gradational with the conglomerate, both laterally and vertically. Sandstone also forms channel-fill deposits as well as the matrix within the conglomerates. The sandstones are composed mainly of angular to subrounded grains of quartz, quartzite, and chert cemented by silica.

FIGURE 6.—Pryor Conglomerate Member of the Kootenai Formation in sec. 28, T. 3 S., R. 9 E., showing repeated reverse graded bedding.

The source for the conglomeratic unit was probably upper Paleozoic and Mesozoic rocks to the west (Lammers, 1939, p. 114), where uplift had taken place during Late Jurassic and Early Cretaceous time. This uplift was probably in central or southeastern Idaho as suggested by Armstrong and Oriel (1965, p. 1854). A western source is also implied by the southeastward pinchout of the Pryor Conglomerate Member in the northern part of the Bighorn Basin (Moberly, 1960, p. 1147). Directional features that include cross stratification, pebble imbrication, current lineations, and ripple marks indicate sediment transport by northeastward-flowing currents. The conglomerate, conglomeratic sandstone, and sandstone of rather uniform thickness were deposited on a surface of very little relief, generally on Morrison coal-bearing swamps. In the vicinity of Livingston, Mont., characteristics such as scour-and-fill structures, crossbedding, poor sorting, local wood fragments, rounded chert pebbles, and current bedding indicate a fluvial origin. The widespread distribution and the generally polished surface, roundness, and concentration of the pebbles suggest that these accumulations were repeatedly reworked, leaving only the most resistant rocks as a lag gravel. The well-rounded and polished chert pebbles were originally interpreted as gastroliths (Hares, 1917); however, additional observations of these widespread pebbles throughout similar sequences led Stokes (1942, p. 18–19) and others to abandon this interpretation in favor of wind polishing prior to deposition.

Overlying the basal Pryor Conglomerate Member is a very poorly exposed sequence of variegated red, purple, green, and gray siltstone, claystone, mudstone, limestone, and tuff that contains nonpersistent beds of sandstone (refer to measured section 1). The unit is of terrestrial origin; the limestone is lacustrine. Some of the beds are tuffaceous or contain claystone of probable volcanic origin.

The part of the Kootenai Formation above the Pryor Conglomerate Member in the area west of Livingston and in the northern part of the Gallatin Range was deposited on an extensive lowland bordered on the west by highlands. Streams from the west dropped their sediment on alluvial fans, in channels, and on flood plains. The grain size of sandstones decreases from west to east, as shown in the stratigraphic sections near Bozeman and Livingston (refer to measured sections 1–3). During the close of deposition of the Kootenai, a very large region including the Livingston area was covered by a lake in which mudstone and limestone were deposited. This lake or series of lakes extended at least from Teton County in northwestern Wyoming (Love, 1956, p. 77) northward into Canada and from Bozeman eastward to Harlowton in central Montana. Aphanocrystalline limestones near Bozeman contain molds of unidentifiable leached fossils; however, southeast of Bozeman, in the NE¼ sec. 25, T. 3 S., R. 6 E. in the Mystic Lake quadrangle (Roberts, 1964g) and in the SE¼ sec. 3, T. 4 S., R. 7 E. in the Maxey Ridge quadrangle (Roberts, 1964e), a very fossiliferous limestone is exposed. This limestone is almost a coquina of small fresh-water gastropods, pelecypods, and ostracodes and is an excellent marker bed for the Kootenai in this part of the report area.

Tuffs and claystones or mudstones in the Kootenai were probably derived, in part, from volcanic ash. Richards (1955, p. 43) described bentonite and bentonitic shale from the middle unit of the Cloverly Formation along the northeast flank of the Bighorn Mountains. In the Bighorn Basin, equivalent strata contain bentonitic mudstone (Moberly, 1960, p. 1145). The volcanic source for these rocks has yet to be defined.

AGE AND CORRELATION

The Kootenai Formation in Montana is considered to be of Early Cretaceous age (fig. 2). In some parts of Montana and northern Wyoming, it contains dinosaur, fish, and turtle bones; plant impressions; fresh-water mollusks; and ostracodes. Over most of western Montana there are one or more limestones, commonly near the top of the formation, that locally contain abundant molds and casts of fresh-water gastropods, pelecypods, and ostracodes. A collection of fresh-water mollusks from the Kootenai Formation near Harlowton, Mont., was described by Stanton (1903, p. 194), who assumed that the fauna was not older than Early Cretaceous and was more probably at about the base of the Upper Cretaceous. R. W. Brown (1946, p. 238) reviewed the floras of the Kootenai and Morrison Formations of Montana and their equivalents in Alberta, Canada, and concluded that the flora above what is now considered the basal part of the Kootenai is Early Cretaceous in age, and the flora below the unconformity at the base of the Kootenai is equivalent to that in the Morrison Formation of Late Jurassic age. Peck (1941, p. 286) identified the charophytes *Atopochara trivolvis*, *Aclistochara mundula*, and *Clavator harisi* and the ostracode *Metacypris angularis* from the upper part of the Kootenai of southwestern Montana and correlated the Kootenai with part of the Trinity Group (Aptian) of Texas. Cobban and Reeside (1952b) also assigned an Aptian age to the Kootenai Formation. Yen (1951, p. 2) described a fluviatile fauna from the Kootenai near Harlowton, Mont. (originally described by Stanton 1903) and correlated part of the formation with the Cloverly Formation in Wyoming and part with the Peterson Limestone of the Gannett Group in Wyoming and Idaho. Near the south border of Glacier National Park the shale and limestone unit at the top of the Kootenai contains *Unio reesideanus* Yen (Cobban, 1955, p. 109), which is presently known only from the Kootenai of Montana or its equivalent.

Along the north shore of Mystic Lake (Roberts, 1964g) in the NE¼ sec. 25, T. 3 S., R. 6 E., a limestone contains ostracodes that are mostly steinkerns. Occasionally, a few poorly preserved fossils were found; however, preservation is generally too poor for generic determination. One species resembles *Cypridea anomala* described by Peck from the Kootenai Formation (I. G. Sohn, written commun., 1963). The same limestone, in sec. 3, T. 4 S., R. 7 E., contains at least two kinds of fresh-water snails. Southwest of Livingston, near Virginia City, Mont., the Kootenai Formation contains *Botryococcus*, a fresh-water algae whose presence suggests lacustrine or possibly deltaic deposition (R. H. Tschudy, written commun., 1962).

THERMOPOLIS SHALE

The Thermopolis Shale was named and described by Lupton (1916, p. 168) for about 700 feet of dark-gray shale and some lenticular sandstone beds exposed in the Bighorn Basin near Thermopolis, north-central Wyoming. Lupton's original Thermopolis Shale was underlain by the Greybull Sandstone Member of the Cloverly Formation that is now included as the basal member of the Thermopolis (as used by Eicher, 1960) (fig. 2). The upper half of his Thermopolis Shale is now the lower part of the Mowry. The Muddy Sandstone is the upper member of the Thermopolis (fig. 2), or a separate formation.

Reeside (1944) first used the term Muddy Sandstone Member of the Thermopolis Shale; however, he continued using Thermopolis Shale as it was originally defined by Lupton (1916, p. 168) and made the Muddy Sandstone the medial member of the Thermopolis. Love (1948, p. 106) and Thompson, Love, and Tourtelot (1949) proposed that the Thermopolis Shale be restricted to the interval between the Cloverly Formation and the Muddy Sandstone Member; that the Muddy Sandstone be considered a formation; and that the shale interval between the Muddy Sandstone and the Mowry Shale be included with the Mowry. Most stratigraphers have adopted these redefinitions as in the Buffalo-Lake De Smet area, Wyoming, Mapel (1959, p. 41) and in the Shotgun Butte area southwest of Thermopolis, Wyo., Keefer and Troyer (1964, p. 18) placed the Thermopolis-Mowry boundary at the top of the Muddy Sandstone Member. In certain areas of central Wyoming the Muddy Sandstone is a mappable unit, but in other areas it is not and is included as the upper member of the Thermopolis Shale (fig. 2).

The basal member of the Thermopolis Shale near Livingston includes a clastic unit equivalent to the Greybull Sandstone Member. Darton (1904, p. 398–399) originally included a similar clastic unit, exposed along the east side of the Bighorn Basin, Wyoming, in the Cloverly Formation. Later, Hintze (1915, p. 15) named the Greybull Sandstone Member and assigned it to the upper part of the Cloverly Formation in north-central Wyoming. Hewett and Lupton (1917, p. 19) defined the boundary between the Thermopolis Shale and Cloverly Formation as the top of the Greybull Sandstone Member of the Cloverly. Subsequent work, however, has shown that the Greybull Sandstone disconformably overlies older rocks, is gradational with the overlying "Rusty beds," and should not be included in the Cloverly. The "Rusty beds" were described by Washburne (1908, p. 350) as the basal member of the Colorado Formation in the Bighorn Basin, Wyoming. Eicher (1960) reviewed the stratigraphy and nomenclature of the Thermopolis Shale and "Rusty beds" and included the "Rusty beds"-Greybull Sandstone interval in the Thermopolis. He also considered the base of the Thermopolis to be disconformable on the Cloverly Formation (1960, p. 15). Most stratigraphers now include these units in the Thermopolis as shown in figure 2. The "Rusty beds" and Greybull Sandstone Member are a persistent transgressive sequence at the base of the marine Cretaceous in north-central Wyoming and south-central Montana.

Iddings and Weed (1894) mapped a unit, the Colorado Formation, in the northern Gallatin Range, which probably includes the Thermopolis Shale, Mowry Shale, and Frontier Formation of this report. They correlated their Colorado Formation with the Benton Shale and the Niobrara Limestone (Iddings and Weed, 1894, p. 2). The massive quartzite in the upper member of their Dakota Sandstone was correlated with the Greybull Sandstone Member of the Cloverly Formation of north-central Wyoming by Lee (1927, p. 65). Calvert (1912a, p. 31) combined the Colorado and Montana Formations of Iddings and Weed as the Colorado Shale. Skeels (1939, p. 817) included the rocks above the Cloverly Formation and beneath the Telegraph Creek(?) Formation as the Colorado Group. He (1939, p. 817) divided the Colorado Group into a lower unit that includes the Thermopolis Shale, Mowry Shale, and Frontier Formation and an upper unit that includes the Carlile and Niobrara Formations. McMannis (1955, p. 1406), in the adjoining area to the northwest in the Bridger Range, combined the poorly exposed sections between the Kootenai Formation and the Eagle Formation as the Colorado Formation. In the adjoining area to the east, Richards (1957, p. 414) mapped the interval between the Kootenai Formation and the Virgelle Sandstone (basal member of the Eagle Sandstone) as the Colorado Shale.

In the Livingston area, the Thermopolis Shale unconformably overlies the Kootenai Formation and is overlain, apparently conformably, by the Mowry Shale. The Thermopolis consists of marine shale and sandstone, including a basal sandstone member that is 35 to 50 feet thick; a middle mudstone or shale member, 350 to 390 feet thick; and an upper sandstone member, 90 to 105 feet thick. The lower sandstone member is probably a near-shore deposit of a transgressing sea; the basal part of the sandstone commonly fills topographic depressions on an underlying erosion surface.

The middle shale member is probably an offshore marine deposit, and the upper sandstone member is probably a regressive near-shore marine and brackish-water deposit. In the Livingston area the upper sandstone member is commonly nonresistant, and for geologic mapping purposes the Thermopolis and overlying Mowry Shales were undifferentiated (Roberts, 1964a–h). The Thermopolis-Mowry unit generally is unexposed between the ridges formed by the Kootenai and Frontier Formations.

LITHOLOGIC COMPOSITION

The Thermopolis Shale in the Livingston area consists of three members (refer to measured section 4). The lower sandstone member consists of thin- to thick-bedded, crossbedded, yellowish-gray, fine- to medium-grained sandstone. The sandstone is composed of well-sorted subrounded grains of quartz and chert and a few grains of magnetite and muscovite. It commonly is irregularly cemented with silica or calcium carbonate. Unequal resistance to weathering of the irregularly or partly cemented sandstone results in raised fretworks on the bedding surfaces on the south flank of Canyon Mountain (figs. 7, 8).

Some beds in the lower sandstone member are quartzose sand. Commonly in local areas of tight folding these sandstone beds have become well indurated and form prominent quartzite ridges. The lower member also contains some interbeds of siltstone that have abundant tracks and trails ascribed to marine bottom-dwelling organisms.

The middle shale member is dominantly shale interbedded with very fine grained sandstone, siltstone, claystone, and bentonite. This member at Livingston is dark

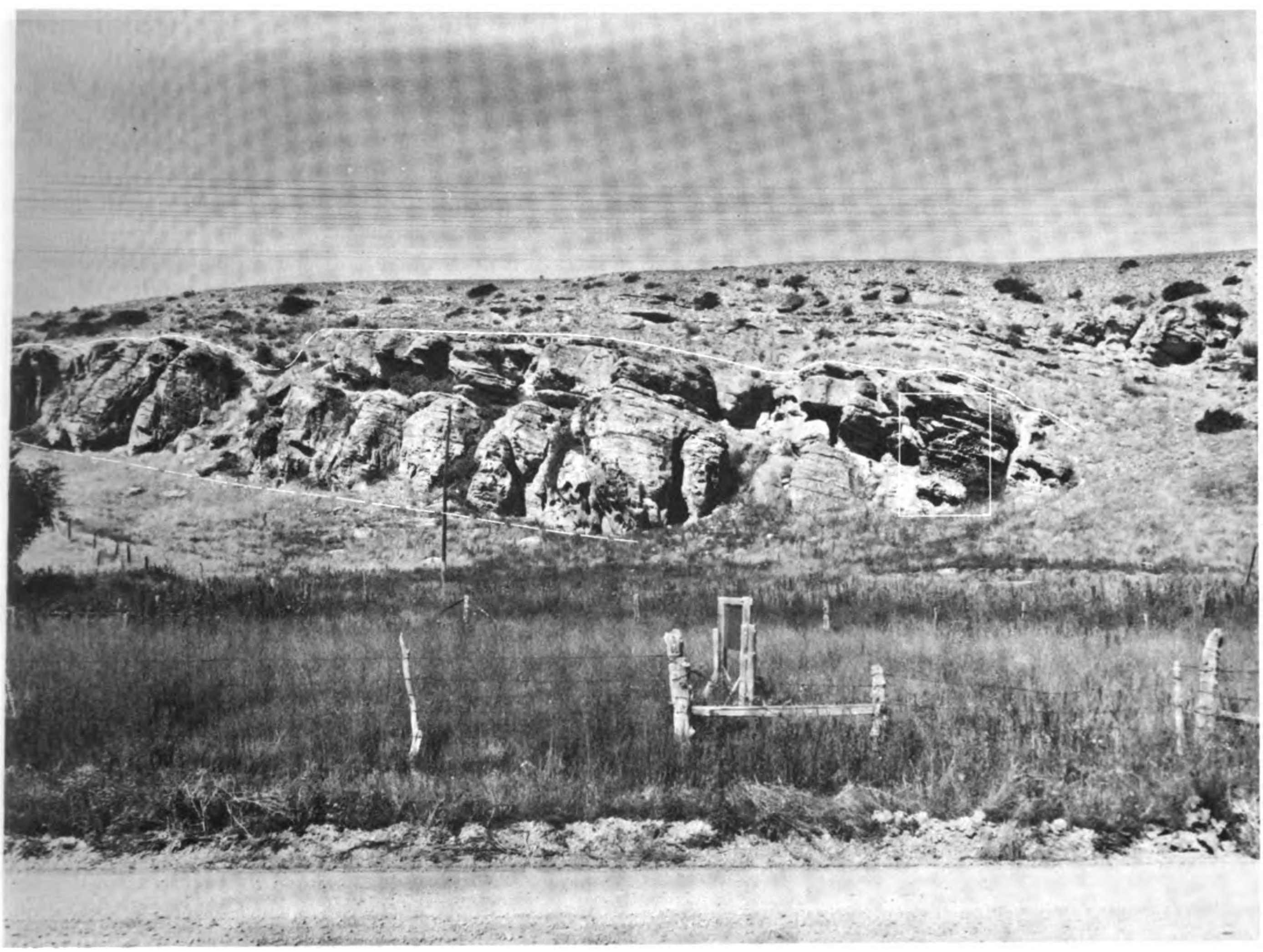


FIGURE 7.—Excellent exposure of the lower sandstone member of the Thermopolis Shale, NE¼ sec. 28, T. 3 S., R. 4 E. Outlined area enlarged in figure 8.

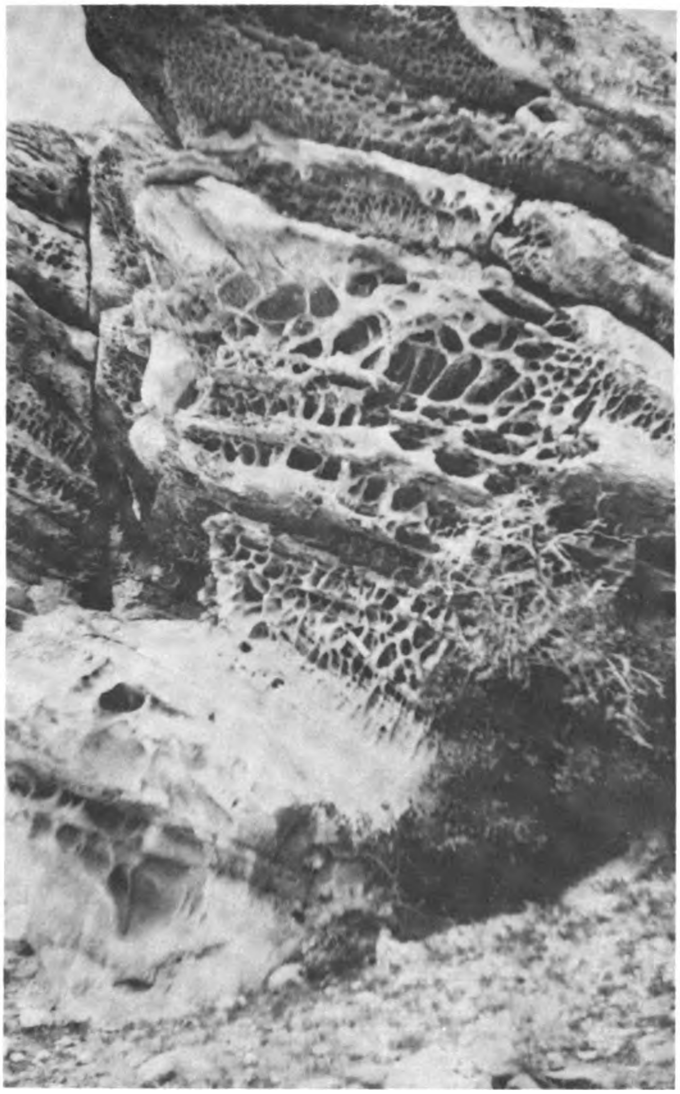


FIGURE 8.—Fretwork, which is on a cliff of crossbedded sandstone of the Thermopolis Shale, is caused by unequal resistance to weathering of the irregularly cemented sand grains. Enlarged view of part of figure 7.

gray and weathers to light gray, whereas the overlying Mowry Shale is dark grayish brown and weathers to grayish yellow green and yellowish gray. The shale is carbonaceous, commonly contains macerated plant fragments, and is commonly calcareous. Sandstones interbedded in the middle shale member are thin bedded, very fine grained, silty, calcareous, and commonly contain plant fragments. Most sandstone bedding surfaces are covered with marine worm trails, groove casts, and other sole marks of undetermined origin.

The upper sandstone member consists of medium- to thick-bedded, crossbedded, medium-gray, fine- to very fine grained (table 1), well-sorted, calcareous sandstone. The sandstones are micaceous, glauconitic, and feldspathic, and they contain a limited heavy-mineral suite of magnetite, pyrite, and biotite. A few sandstone beds contain claystone pebbles. Some large plant fragments and carbonaceous trash were noted on bedding surfaces. Bedding surfaces are commonly ripple marked, and many have worm(?) trails and groove and small flute casts.

AGE AND CORRELATION

In the northern part of the Gallatin Range and to the southeast in Wyoming the Thermopolis Shale consists of three members: a lower sandstone member, correlative with the "Rusty beds" and Greybull Sandstone Member of north-central Wyoming; a middle shale member, correlative with the Skull Creek Shale of northeastern Wyoming; and an upper sandstone member correlative with the Muddy Sandstone Member in central Wyoming (fig. 2).

The lower sandstone member correlates with the "First Cat Creek Sand" in central Montana and is in the stratigraphic position of the Fall River Formation of the Black Hills area (Cobban, 1951, p. 2173–2175); however, between central Montana and the Black Hills this interval of rock changes to a silt or shale facies. The Birdhead Sandstone Member of the Thermopolis Shale as used by Thom, Hall, Wegemann, and Moulton (1935, p. 47) southeast of Billings, Mont., and the lower sandstone member at Livingston have similar mineralogy and clay-pebble constituents and are presumed to be stratigraphic equivalents. The upper sandstone member is also in about the same stratigraphic position as the Newcastle Sandstone of the Black Hills area but the sand facies is discontinuous between the two areas.

The hiatus between the Kootenai Formation and the Thermopolis Shale is presumed to be short inasmuch as the index fossil *Protelliptio douglassi* occurs immediately above and below the widespread disconformity that separates the two formations. Stanton (1903, p. 195) and Yen (1951, p. 3) identified this fossil from beds near the top of the Kootenai Formation in south-central Montana, near Harlowton. Cobban (in Waagé, 1959, p. 63, 72) identified this fossil from the basal bed of the Fall River Formation in northeastern Wyoming, near Devils Tower. Waagé (1959, p. 52–55) referred to this stratigraphic break as a transgressive disconformity and discussed its different features at various localities in the Black Hills. Waagé (1955, p. 47–48) had previously discussed a stratigraphically similar disconformity along the northern Front Range in Colorado. In the Bighorn Basin, Eicher (1960, p. 15) and Moberly (1960, p. 1155) believe that this same disconformity is present at the top of the Cloverly Formation. The evidence thus indicates that the disconformity apparently extends over much of Montana, Wyoming, and Colorado.

TABLE 1.—*Grain-size distribution and heavy-mineral content in sandstones of the Thermopolis Shale, Frontier Formation, Cody Shale, Telegraph Creek Formation, and Eagle Sandstone near Livingston, Mont.*

[All data, in percent; indicated diameter, in millimeters. Tr., trace; N.d., not determined. Analyses, by R. F. Gantnier]

Stratigraphic name, measured section, and unit sampled	Soluble in acid	Grain-size distribution for indicated diameter												Heavy minerals in sample
		4.0	2.0	1.0	0.5	0.25	0.125	0.062	<0.062	0.05	0.005	0.002	<0.002	
Eagle Sandstone:														
Section 14, unit 59	33.4						38.9	51.0	10.1					0.40
30	15.7				Tr.	11.2	61.3	16.1		1.4	6.4	0.7	2.9	.28
Eagle Sandstone, Virgelle Sandstone Member:														
Section 14, unit 23	20.14				0.01	12.59	64.30	11.96	11.14					.59
21	23.75		0.8	0.17	.44	18.78	47.28	14.96	18.26					.15
1 (top)	19.5					.01	62.2	25.9		2.7	5.6	1.2	2.4	N.d.
1 (base)	57.02				.03	.28	33.21	44.94	21.54					.17
Telegraph Creek Formation:														
Section 12, unit 7	35.16					.03	7.45	61.79	30.73					.32
Cody Shale, Eldridge Creek Member:														
Section 11, unit 13	13.0						5.5	68.2		5.3	16.6	.8	3.6	.16
Frontier Formation:														
Section 10, unit 26	.9	0.2	.3	.2	.1	26.9	66.4	2.8	3.0					N.d.
18	1.19		.1	Tr.	.1	7.8	75.6	8.9	7.5					.21
6	.81				.04	7.74	75.78	10.01	6.43					.40
Thermopolis Shale, upper sandstone member:														
Section 5, unit 17	17.70					.05	20.54	62.11	17.30					.37

A fairly complete succession of plant microfossils from measured stratigraphic section 4 of the middle shale and upper sandstone members of the Thermopolis Shale and from measured section 7 of the lower Mowry Shale of the Livingston area is listed in table 2. Photographs of these assemblages are given in Tschudy and Veach (1965). R. H. Tschudy (written commun., 1965) made the following generalizations pertaining to this faunal succession:

1. The S_1–p group (S_1–p13, S_1–p14, and S_1–p15) characterizes the lower Thermopolis Shale samples.
2. Only one species of angiosperm tricolpate pollen is present in the composited lower Thermopolis sample from U.S. Geological Survey (USGS) Paleobotany localities D3512–A, B, C, and D; the number of species of this pollen type increases in the sample from USGS Paleobotany locality D3512–H.
3. Few angiosperm pollen were found, and all species found belong to the tricolpate group. This finding agrees with information from other parts of the world that unequivocal angiosperm pollen first appeared in the Albian, and there only as tricolpate pollen. No evolutionarily more advanced forms are known from the Albian.
4. In samples from USGS Paleobotany localities D3512–N and U large spores are dominant, particularly species of *Cicatricosisporites* and *Appendicisporites*.
5. The easily recognized and distinctive species of cf. *Trilobosporites* (TT–rt11) is absent from the Thermopolis, but common in the Mowry samples.

Samples from the Skull Creek Shale on the east side of the Bighorn Mountains, measured section 6 (USGS Paleobotany locs. D3842–A, B), yielded a diagnostic pollen and spore flora (table 3) according to R. H. Tschudy (written commun., 1967). He found that samples from localities D3842–A (42 feet above the base of the Skull Creek Shale) and D3842–B (58 feet above the base of the Skull Creek Shale) contained eight species of monosulcate pollen and two species of tricolpate pollen. This assemblage suggests a correlation with locality D3512–H (167 feet above the base of the Thermopolis Shale at the Livingston reference section 4, unit 18). The number of monosulcate pollen species found decreases with decreasing age in this part of the section.

Few macrofossils have been reported from the middle shale member or its equivalent Skull Creek Shale, and none was collected in the Livingston area during the present investigation. Cobban (1951, p. 2176) listed an Early Cretaceous (Albian) marine fauna collected in central Montana from equivalent black shales assigned to the Colorado Shale.

MOWRY SHALE

Darton (1904, p. 400) named the "Mowrie beds" from exposures of marine shale on Mowrie Creek northwest of Buffalo, Wyo., in the northern end of the Bighorn Mountains. Mowry has been the approved spelling since 1906 (Darton, 1906, p. 53). Darton and O'Harra (1909, p. 4), in their brief description of the Cretaceous section in the Belle Fourche quadrangle in the Black Hills, S. Dak., considered the Mowry to be a member in the Graneros Shale of the Benton Group of Late Cretaceous

TABLE 2.—*Checklist of plant and miscellaneous microfossils from the Thermopolis and lower Mowry Shales near Livingston, Mont*

[Identifications by R. H. Tschudy]

Provisional palynomorph genera	Code species	Thermopolis Shale (measured section 4, USGS Paleobotany locality D3512-)				Mowry Shale (measured section 7, USGS Paleobotany locality D3513-)	
		A, B, C, D	H	N	U	A	B
Gleicheniidites	cf. Gleich 2	×	×	×	×	×	
Gleicheniidites	Gleich 9	×	×	×			
cf. *Cyathidites*	TC-sm9	×					
cf. *Concavissimisporites*	TT-r3B	×	×	×			
Lycopodiumsporites	TO-rt14B	×					
cf. *Concavissimisporites*	TC-sp1	×					
Cicatricosisporites	AN-13	×	×	×	×	×	×
Abietineaepollenites	V_2S-sm9	×	×	×	×		
Abietineaepollenites	V_2L-r5	×					
Abietineaepollenites	V_2L-sm21	×		×			
Rugubivesiculites	V_2S-rug3	×	×				
Vitreisporites	V_2L-sm2	×	×	×	×		×
Classopollis	Classo 1	×	×	×	×	×	
Inaperturopollenites	cf. Tax-p13	×					
Inaperturopollenites	Tax-sm1	×	×	×	×		×
Inaperturopollenites	Tax-r6	×	×		×	×	×
Araucariacites	S_1-sm16	×		×			
Monosulcites	S_1-sm5c	×	×				
Monosulcites	S_1-r32	×	×				
Monosulcites	S_1-p14	×	×	×			
Monosulcites	S_1-p15	×	×				
Monosulcites	S_1-p13	×	×				
Tricolpopollenites	C_3-rt4	×			×		×
Alga-dinoflagellate	Din-D	×					
Alga-hystrichosphere	Hys-sim14	×					
Lycopodiumsporites	TT-rt17		×				
Gleicheniidites	cf. Gleich 2c		×	×		×	×
Abietineaepollenites	V_2L-sm4		×				
Alga-dinoflagellate	DOn-A17		×				
?	TT-p28		×				
Cicatricosisporites	An-15		×	×		×	
?	To-sp15		×				
Klukisporites	TT-rt16B		×	×		×	×
Lycopodiumsporites	TT-rt5		×				
cf. *Stereisporites*	Ea-r1		×				
cf. *Osmundacidites*	To-p7c		×				
Tricolpopollenites	C_3-rt34		×				
Tricolpopollenites	C_3-r16B		×				
Eucommiidites	C_3-sm18		×	×	×	×	×
Tricolpopollenites	C_3-r16		×	×			
Tricolpopollenites	C_3-rt6		×	×			
Araucariacites	S_1-r15		×				
Decussosporites	S_1-r30		×				
Inaperturopollenites	Tax-r2		×				
Monosulcites	S_1-sm6		×				
Monosulcites	S_1-r31		×				
Abietineaepollenites	V_2L-sm20		×	×	×		×
Lycopodiumsporites	TO-rt14		×	×	×		
?	O-sp11		×				
Alga-dinoflagellate	Din-C_2		×				
Hamulatisporis	TO-rug1			×	×	×	
cf. *Plicatella*	App-12			×			
cf. *Todisporites*	TT-sm10			×		×	
?	TO-r1			×			
Eucommiidites	C_3-sm15			×	×	×	
cf. *Applanopsis*	Vun-rug2			×	×		
Taurocusporites	Tauro-6			×			
Alga-?*Pachysphaera*	cf. O-fov1			×			
Aequitriradites	Fmem-sp3			×			
?	O-sp9			×			
Appendicisporites	App-11			×	×	×	
cf. *Parvisaccites*	V_2S-rt3			×			
Araucariacites?	cf. S_1-P1			×			
?	TT-p29			×			
?	TC-p4			×			
cf. *Deltoidospora*	TT-sm36			×			
Hamulatisporis	TO-rug24B			×			
?	TO-p2			×			
Cicatricosisporites	An-19C			×			
Cicatricosisporites	An-1			×			

TABLE 2.—*Checklist of plant and miscellaneous microfossils from the Thermopolis and lower Mowry Shales near Livingston, Mont.*—Con.

Provisional palynomorph genera	Code species	Thermopolis Shale (measured section 4, USGS Paleobotany locality D3512-)				Mowry Shale (measured section 7, USGS Paleobotany locality D3513-)	
		A, B, C, D	H	N	U	A	B
Cicatricosisporites	An–16c			×	×		
Araucariacites	S_1–r18			×	×	×	×
Abietineaepollenites	V_2S–r14			×			
?	TC–r5			×			
Cicatricosisporites	An–16			×		×	
cf. *Cingulatisporites*	Fdens–sm3			×	×		
Alga-dinoflagellate	Din–D4			×			
cf. *Deltoidospora*	TC–sm4E				×		
?	TC–p5				×		
cf. *Plicatella*	App–7				×		
Appendicisporites	App–1				×		×
?	TT–sm31B				×		
Alga-hystrichosphere	Tub–com1				×		
Alga-dinoflagellate	Din–B10				×		
Tricolpopollenites	C_3–r10				×		
cf. *Deltoidospora*	TT–sm4				×		
Verrucosisporites	TO–p3B				×		
Appendicisporites	APP–4B				×		
Lycopodiumsporites	TT–rt15				×		
cf. *Aequitriradites*	FMem–sp2				×		
cf. *Deltoidospora*	TT–sm9				×		
Pilosisporites	TT–sp13				×		
Abietineaepollenites	V_2S–sm29				×		
Abietineaepollenites	V_2L–sm7				×		
?	TT–r9B				×		
Trilobosporites	TC–p1C					×	
cf. *Plicatella*	App10					×	
cf. *Trilobosporites*	TT–rt11					×	×
Acanthotriletes	TT–sp12					×	
cf. *Eucommiidites*	C_3–sm14					×	
Monosulcites	S_1–sm11					×	
Tricolpopollenites	C_3–rt23C					×	
Vitreisporites	V_2L–sm2C					×	
Tricolpopollenites	C_3–rt14					×	
Cicatricosisporites	An–8					×	
Trilobosporites	TC–p1D					×	
cf. *Deltoidospora*	TC–sm4H					×	
cf. *Biretisporites*	TT–sm4B					×	
cf. *Deltoidospora*	TT–sm7					×	
cf. *Cyathidites*	cf. TC–sm10					×	
Operculites	Szon–sm4					×	
Abietineaepollenites	V_2S–sm26					×	
cf. *Concsavisporites*	TC–sm8						×
Trilobodporites	cf. TC–p1						×
Appenieicisporites	App–4						×
Lecanlplla	O–rt11						×
Tricoaopollenites	C_3–rt18B						×
Araucriacites	cf. S_1–r10						×
?	Vun–rug3B						×
Abietineaepollenites	V_2L–sm8						×
?	O–sp10						×
Acanthotriletes	TO–sp14						×
Monosulcites	S_1–rt21						×

age. In the western Black Hills of Wyoming, Hancock (1920, p. 39) similarly placed the Mowry as a member in the Graneros Shale, but of the Colorado Group. Collier (1922, p. 76) separated the basal 25–50 feet of the Mowry Member of the Graneros Shale and designated these soft, dark-shale beds and thin sandy lenses as the Nefsy Shale Member of the Graneros. Rubey (1931, p. 4), in discussing the lithologies of Upper Cretaceous formations in northeastern Wyoming and southeastern Montana, used the name Mowry Siliceous Shale Member of the Graneros Shale, which included beds equivalent to the Nefsy. The Mowry Shale was considered of formation rank by Reeside (1944) in his study of Cretaceous deposits in the western interior of the United States, and many later geologists agreed with this rank. For a comprehensive historical treatment of the application of the name Mowry, the reader is referred to Reeside and Cobban (1960).

TABLE 3.—*Checklist of plant and miscellaneous microfossils from the Skull Creek Shale and Mowry Shale reference section near Buffalo, Wyo.*

[Identifications by R. H. Tschudy]

Provisional palynomorph genera	Code species	Skull Creek Shale (USGS Paleobotany locality D3842-)[1]			Mowry Shale (USGS Paleobotany locality D3843-)[2]					
		A	B	C	A	B	C	D	E	F
Modern contaminants	Compositae and pine contaminants.	X	X		X					
Alga-dinoflagellate	Din-C2	X	X					X		
Alga-dinoflagellate	Din-A17	X	X							
Alga-hystrichosphere	Hystrichospheres	X	X					X	X	
Alga-*Pterospermopsis*	*Pterospermopsis*	X	X				X	X	X	X
Acanthotriletes	TT-sp12	X								
Monosulcites	S_1-p14	X			X					
Abietineaepollenites	V_2S-sm9	X								
Araucariacites	S_1-r18	X			X		X			
Gleicheniidites	Gleich-2	X	X				X	X	X	
Inaperturopollenites	Tax-sp	X								
cf. *Applanopsis*	Vun-rug2	X								
Abietineaepollenites	V_2S-sm29	X								
Monosulcites	S_1-r32	X			X					
Monosulcites	S_1-sm5C	X								X
cf. *Concavisporites*	TC-sm8	X	X							
Tricolpopollenites	C_3-rt6		X				X			
Abietineaepollenites	V_2L-sm20		X	X			X		X	X
Monosulcites	S_1-r31		X							
Monosulcites	S_1-p15		X							
Araucariacites	S_1-sm16		X	X		X				
Vitreisporites	V_2L-sm2		X				X	X	X	
Tricolpopollenites	C_3-r16		X		X					
Monosulcites	S_1-rt (new)		X							
Alga?-*Schizocystia*	*Schizocystia*		X	X	X	X				
Inaperturopollenites	Tax-sm1			X						
Monosulcites	S_1-sm11			X						
Araucariacites	S_1-r10				X					
Ovodites	*Ovoidites*				X					
Monosulcites	S_1-sm6C				X		X			
Alga-*Tetraporina*	*Tetraporina*				X					
Schizosporus	*Schizosporis*				X					
Monosulcites	S_1-rt21					X				
Alga?-*Lecaniella*	O-rt11					X			X	
?	O-sp11					X	X			
Inaperturopollenites	Tax-r2						X	X		
Rugubivesiculites	V_2S-rug3						X		X	
Classopollis	Classo-1						X	X	X	
cf. *Todisporites*	TT-sm10						X			
Eucommiidites	C_3-sm18						X		X	X
Lycopodiumsporites	TO-rt14						X		X	
?	Vun-rug3B						X			
Alga-dinoflagellate	Din-D4							X		
Inaperturopollenites	Tax-r6							X	X	
Tricolpopollenites	C_3-rt4							X	X	
cf. *Eucommiidites*	C_3-sm14							X		
cf. *Cyathidites*	TC-sm10							X	X	
Tricolpopollenites	C_3-rt14							X	X	
Cicatricosisporites	An-13								X	
cf. *Cingulatisporites*	Fdens-sm3								X	
Tricolpopollenites	C_3-r10								X	
Abietineaepollenites	V_2L-sm8								X	X
cf. *Deltoidospora*	TT-sm7								X	
Araucariacites?	S_1-p1								X	
Hamulatisporis	TO-rug1								X	
?	O-sp10								X	
cf. *Concavissimisporites*	TT-r3B								X	
Cicatricosisporites	An-16C								X	
Tricolpopollenites	C_3-rt (new)								X	
Lycopodiumsporites	TO-rt1								X	
Eucommiidites	C_3-sm15								X	
Alga-dinoflagellate	Dino (new)								X	X

[1] For measured section refer to Mapel (1959, p. 39) and measured section 6 of the present report; A, 42 ft above base of Skull Creek Shale; B, 58 ft above base of Skull Creek Shale; and C, 144 ft above base of Skull Creek Shale.
[2] For measured section refer to Mapel (1959, p. 42); A, 5 ft above base of Mowry Shale; B, 35 ft above base of Mowry Shale; C, 172 ft above base of Mowry Shale; D, 332 ft base of Mowry Shale; E, 476 ft above base of Mowry Shale; and F, 510 ft above base of Mowry Shale.

Mapel (1959, p. 42) measured and described the Mowry Shale 1½ miles south of Darton's undescribed section, and Mapel's section is herein designated the typical section for the Mowry. Mapel included 202 feet of grayish-black shale and interbedded bentonite as the basal "black shale member" that was earlier part of the Thermopolis Shale (refer to discussion under general features of the Thermopolis Shale in this report).

The Mowry Shale is characteristically siliceous, and, according to Rubey (1929), the silica owes its origin to the alteration of volcanic ash. Reeside (1957, p. 517) indicated that the thin and regular bedding of the Mowry Shale suggests deposition in quiet and perhaps deep water. Rubey (1929, p. 156, 168) suggested extremely slow deposition on the basis of the large amount of organic material and the widespread abundance of fish scales and other chemically resistant parts of fish, in contrast with the relative scarcity of shells and bones.

The Mowry Shale in the Livingston area conformably overlies the upper sandstone member of the Thermopolis Shale, and it ranges in thickness from 430 to 500 feet. Near Buffalo, Wyo., the Mowry typical section is 527 feet thick (Mapel, 1959, p. 42). Near Thermopolis, Wyo., the Mowry is 560 feet thick (Keefer and Troyer, 1964, p. 18). At the north end of the Pryor Mountains, Mont., the Mowry is 495 feet thick. Near Great Falls, Mont., the stratigraphic equivalent of the Mowry is 330 feet thick (Cobban and others, 1959, p. 2793).

LITHOLOGIC COMPOSITION

The Mowry Shale in the Livingston area consists of thin-bedded to massive, silty, micaceous, dark-gray to dark-brown shale and mudstone that contain scattered interbeds of sandstone, siltstone, claystone, and bentonite. The shale is tuffaceous and readily weathers to clay. The sandstones are very fine to coarse grained, are poorly sorted, contain much silt in the matrix, and are generally calcareous or siliceous.

Two measured sections (7, 8) of the Mowry Shale are about 15 miles apart and are remarkably different. The entire sequence at Rocky Creek Canyon is dominantly tuffaceous; it contains very carbonaceous beds, which bear large plant fragments and thin streaks of coal that suggest deposition in quiet brackish water. On the north flank of Canyon Mountain, the formation is dominantly massive-bedded mudstone and silty shale that is micaceous, pyritic, and generally glauconitic; these rocks suggest shallow restricted marine deposition. The section at Rocky Creek Canyon is 25 percent sand, whereas the section at Canyon Mountain is only 5 percent sand.

In the Livingston area, the Mowry Shale can generally be distinguished from the Thermopolis Shale on the basis of lithology, weathering characteristics, and color. The Thermopolis is dominantly fissile, and the Mowry is dominantly nonfissile. Also, the Thermopolis Shale is dark gray, weathers to light gray, and is not very tuffaceous; whereas, the Mowry Shale is brownish gray, weathers to yellowish gray, and is very tuffaceous. Porcelanitic sandstones are present in the upper 200 feet of the Mowry.

AGE AND CORRELATION

Before 1951, most workers considered the Mowry Shale to be Late Cretaceous in age. Cobban and Reeside (1951) first assigned the Mowry Shale of the western flanks of the Black Hills and Mowry equivalents in Colorado, Montana, and Wyoming to the Early Cretaceous. On the basis of ammonites, they indicated that the age of the Mowry was late Albian (as shown in fig. 2).

Nine samples from measured sections 6 and 9 (the Skull Creek Shale and the Mowry Shale typical section near Buffalo, Wyo.) were collected to obtain pollen floras for comparison with floras from the Thermopolis and Mowry Shales near Livingston, Mont. The Wyoming samples (table 3), with exception of those from USGS Paleobotany localities D3842–A, D3842–B, and D3843–E, contained corroded assemblages that had few pollen or spores but many marine forms such as hystrichospheres, dinoflagellates, or *Pterospermopsis;* all the samples lacked the large spores so characteristic of samples of the Thermopolis and Mowry near Livingston (table 2). These facts suggest that the shales at Buffalo, Wyo., were deposited farther from shore under more open water marine conditions than were the equivalent shales at Livingston, Mont.

According to R. H. Tschudy (written commun., 1967), the absence of the larger spores in the Wyoming samples makes direct correlation very difficult. However, when considered as a whole, the fossil assemblages shown on table 3 demonstrate several trends that may be useful. The samples have been plotted in stratigraphic sequence, and changes in fossil content are evident. The most prominent changes are seen if one compares the samples that yielded the best assemblages. The possible correlation of samples from USGS Paleobotany localities D3842–A (42 feet above the base of the Skull Creek Shale) and D3842–B (58 feet above the base) with the sample from USGS Paleobotany locality D3512–H (167 feet above the base of the Livingston Thermopolis Shale reference section) has already been discussed. The number of monosulcate pollen species found decreases with decreasing age in this part of the section. The Mowry Shale samples from Wyoming, particularly those from locality D3843–E, contained a few species found only in the Mowry Shale—namely, Vun–rug3B, V_2L–sm8, O–sp10, O–rt11, TT–sm7, and C_3–rt14. This assemblage correlates with those (table 2) from the Livingston Mowry section.

UPPER CRETACEOUS SERIES

The Upper Cretaceous Series in the Livingston area consists of the Frontier Formation, Cody Shale, Telegraph Creek Formation, Eagle Sandstone, Cokedale Formation, Miner Creek Formation, Billman Creek Formation, Hoppers Formation, and the basal part of the Fort Union Formation. These strata are 10,830 feet thick and are characterized by dark-gray shale interbedded with quartzose siltstone and sandstone. Conglomerates derived from Precambrian metamorphic, Paleozoic and Mesozoic sedimentary, and Cretaceous volcanic rocks occur, in addition, in the upper part.

FRONTIER FORMATION

The Mowry Shale (Lower Cretaceous) is overlain with apparent conformity by a sequence of conglomerate, sandstone, siltstone, and shale that contains thin interbeds of carbonaceous shale and coal. These strata are assigned to the Frontier Formation of Late Cretaceous age. The boundary between the Mowry Shale and Frontier Formation in the Livingston area is the base of the lowest well-defined sandstone of the Boulder River Sandstone Member of the Frontier (Roberts, 1965). The top of the Frontier Formation is placed at the top of the uppermost thick sandstone unit. In this area, the Frontier Formation is conformably overlain by the Cody Shale.

Knight (1902, p. 721) named and described the Frontier Formation from exposures near Kemmerer in southwestern Wyoming. Subsequent workers have assigned the name Frontier to equivalent or partly equivalent beds in Wyoming and adjacent States. For a comprehensive review of the nomenclatural history of the Frontier before 1952, the reader is referred to Cobban and Reeside (1952a). They include a detailed section of the type Frontier in Cumberland Gap near Kemmerer and make lithologic and faunal comparisons of the type section with Frontier sections in nearby areas of Colorado, Montana, Utah, and Wyoming.

Hintze (1915) proposed the names Peay Sandstone and Torchlight Sandstone for prominent sandstone units in the Colorado Formation in a part of the Bighorn Basin of northern Wyoming. Lupton (1916) assigned the sequence in the Bighorn Basin that includes these two sandstone units and the intervening shale to the Frontier Formation and retained Hintze's Peay and Torchlight Sandstones as members. Knappen and Moulton (1931, p. 32–33) applied the formation and member names that were established by Lupton to correlative rocks in the Bridger area of southern Montana. Cobban and Reeside (1952a) extended the use of the name Frontier westward to Columbus, Mont.; Garbarini (1957) continued the correlation westward to McLeod, Mont.; and Roberts (1965) extended the use of the name farther west into the area near Livingston, Mont.

East of the Livingston area, Richards (1957, p. 415) named a prominent 100-foot-thick sandstone unit exposed along the west side of the Boulder River valley near McLeod, Mont., the Boulder River Sandstone Member of the Colorado Shale. This unit represents the basal part of the Frontier Formation of McLeod, Mont., and adjacent areas and was redesignated as the basal member of the Frontier Formation by Roberts (1965, p. B58).

Thickness of the Frontier Formation in southwestern Montana seems uniform on the basis of a few control points. At Livingston the thickness is 415 feet; to the south at Gardiner, Mont., the thickness is 416 feet (Brown, 1957, p. 89); and to the east at Bridger, Mont., the thickness is 418 feet (Knappen and Moulton, 1931, p. 33).

LITHOLOGIC COMPOSITION

The Frontier Formation near Livingston is divided into two general lithologic units—a basal series of well-indurated sandstone in the Boulder River Sandstone Member, and less well-indurated sequence of shale, siltstone, and sandstone in the overlying part of the formation. The basal sandstone forms ridges along the flanks of the major anticlines south of Livingston, opposite the north end of the Gallatin Range. The overlying sequence is not generally exposed, except in the beds of a few consequent intermittent streams.

The lithology and other physical characteristics of the Frontier Formation are presented in measured section 10. The Boulder River Sandstone Member is a sequence of light- to dark-gray to grayish-green, poorly sorted, very fine grained to conglomeratic sandstone that contains fairly abundant heavy minerals, lithic chert, glauconite, and rounded gray or brown chert pebbles. The sandstone is commonly cemented by a calcareous matrix of silt or clay. The beds are thin to massive and locally crossbedded (fig. 9). Thickness of the Boulder River Sandstone Member is uniform in the Livingston area and ranges from 115 to 120 feet.

The upper part of the Frontier Formation in the Livingston area consists of 300 feet of sandstone and shale or siltstone in alternating beds. The sandstone is generally calcite cemented and forms low ridges. The siltstone and shale are commonly carbonaceous and locally contain very thin beds of coal. Sandstone beds are thin to massive, and the sandstone is gray to greenish gray, glauconitic, and fairly well sorted to poorly sorted. The

FIGURE 9.—Prominent 10-foot-thick sandstone unit 32 feet above the base of the Boulder River Sandstone Member of the Frontier Formation, exposed in the SE¼ sec. 27, T. 2 S., R. 9 E. Unit contains abundant chert pebbles typical of the Frontier Formation.

sand grains are mostly quartz, andesine-feldspar, and chert. Heavy minerals include magnetite, zircon, biotite, muscovite, hornblende, anatase, epidote, sphene, sillimanite, staurolite, tourmaline, corundum, garnet, and topaz. Grain-size distribution in the sandstones is domimantly 0.25 mm to $<$0.062 mm as shown on table 1 and is similar to sandstones in the Virgelle Sandstone Member of the Eagle Sandstone.

A conglomerate bed 300 feet above the base of the Frontier, mapped as "C" bed southwest of Livingston by Roberts (1964b; 1964e; 1964f), is a persistent lag deposit that consists of pebbly sandstone in local shallow channels. The unit is thickest and most conglomeratic in the Chimney Rock quadrangle on the north flank of Antelope Butte (Roberts, 1964b). The conglomerate generally contains well-rounded chert pebbles less than 2 inches in diameter in a sand matrix. Garbarini (1957, p. 98) noted a similar chert-pebble conglomerate 300 feet above the base of the Frontier at McLeod, Mont., and L. W. McGrew (oral commun., 1968) found a similar chert-pebble conglomerate in the Frontier near Ringling, Mont. Sandstone units at the top of the Frontier Formation in the northwestern part of the Wind River Basin, Wyo., contain numerous black and brown chert pebbles (Keefer, 1957, p. 184).

Many fine-grained sandstone units in the Frontier contain silt and (or) clay that has been extensively reworked by bottom-dwelling organisms. Casts of *Ophiomorpha* (*Halymenites*) in sandstone beds of the Boulder River Sandstone Member are common (fig. 10). Ripple-marked surfaces and crossbedding are also conspicuous in beds of the Boulder River Sandstone Member.

Porcelanite beds, commonly present in the Frontier Formation in other parts of Montana and Wyoming, are absent near Livingston, although a 45-foot-thick sandstone unit at the top of the Boulder River Sandstone Member has some resemblance to porcelanite (measured section 10, unit 6). The rock is mottled dark gray and medium light gray; it is very fine grained, feldspathic, and micaceous and contains some heavy minerals. Mottling, resembling porcelanite texture, is due to crystallization clusters of analcime in the cementing material. Weathered surfaces have a knobby conglomeratic appearance caused by the erosion of less resistant material between the clusters of analcime (fig. 10). This distinctive surface texture makes this unit an excellent marker bed. It was mapped as the "A" bed by Roberts (1964b, d–f, h).

Bentonites are common in the Frontier Formation in parts of south-central Montana and northwestern Wyoming; however, none were observed in the Frontier near Livingston. This is probably because the strand line was near Livingston during Frontier time, and the volcanic ash that elsewhere formed bentonite was

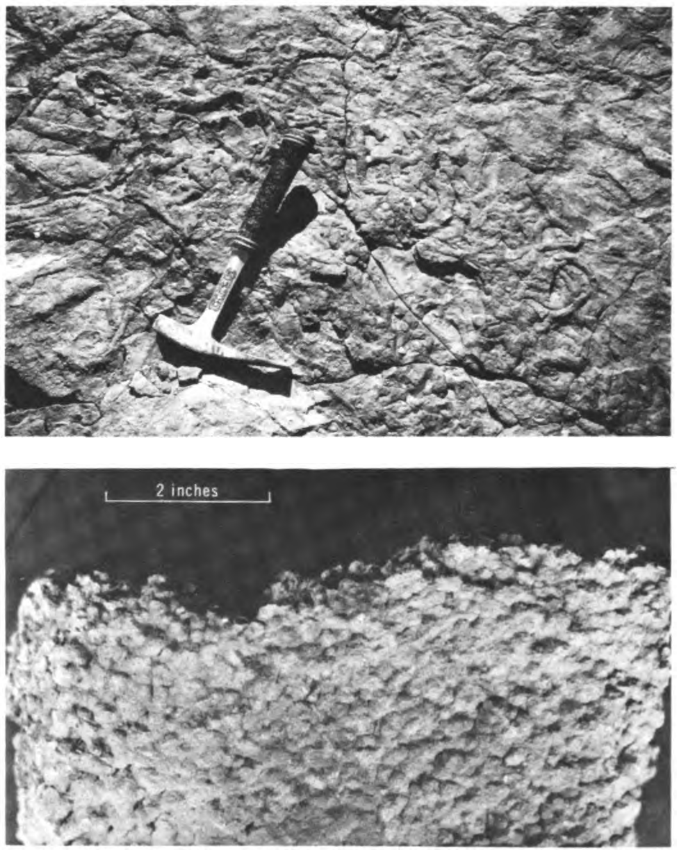


FIGURE 10.—Boulder River Sandstone Member of the Frontier Formation in the SE¼ sec. 27, T. 2 S., R. 9 E. Upper: Casts of *Ophiomorpha* and other burrows on a bedding surface near the base of the member. Lower: Analcime-bearing sandstone in the upper part of the member; conglomeratic appearance caused by weathering of less resistant material between clusters of analcime in the cement.

dispersed in the high-energy near-shore or beach environment. Many of the sandstone units, however, contain zeolite minerals as a part of the cementing matrix. Bradley (1930, p. 4–6 and Slaughter and Earley (1965, p. 70) identified the zeolite minerals in the Frontier-Mowry sequence in parts of Wyoming as alteration products of volcanic ash.

Sediments of the Frontier Formation in the Livingston area were deposited in shallow, brackish water in an oscillating but generally regressing Late Cretaceous sea. Alternating fine- and coarse-grained units, lenticularity of beds, rapid lithofacies changes, a high carbonaceous content including very thin coal beds, and the spore and pollen floras suggest this interpretation. The sudden deposition in much of Montana and western Wyoming of coarse sand and pebbles of the Frontier over the shale of the Mowry suggests an onset of regional uplift, at that time, in the source area for the Cretaceous rocks. The gradual increase in grain size to the west indicates an uplift that may have been centered in western Montana and (or) Idaho. In a comprehensive regional study of bentonites in the Mowry Shale and Frontier Formation, Slaughter and Earley (1965, p. 91) suggested that the airborne ash, which now forms the bentonites, came from multiple scattered sources in the vicinity of, or just east of, the present Idaho batholith, and that the bentonites may be the product of volcanism accompanying emplacement of the batholith.

Many writers, including Cobban and Reeside (1952a), Knechtel and Patterson (1956, p. 18; 1962, p. 914), Hose (1955, p. 59), Van Houten (1962, p. 225), and Slaughter and Earley (1965), have described bentonite beds in the Frontier Formation in different parts of Montana and Wyoming; near Harlowton and McLeod, however, bentonite beds are absent, and the bentonite may have been altered to siliceous beds, or the volcanic ash may have been destroyed in the high-energy shallow-water depositional environment.

Richards (1957, p. 416) noted that intercalated dark-gray shales in a 290-foot-thick interbedded shale and sandstone unit above the Boulder River Sandstone Member at McLeod are similar to the dark-gray shales of the Mowry. In the Livingston area, however, the shale above the Boulder River Sandstone differs in several ways from shale in the Mowry. The Mowry Shale is generally massively bedded, dark grayish brown, micaceous, pyritic, and interbedded with thin to medium beds of well-sorted glauconitic sandstone. Several of the shale units contain reddish-brown specks of hematite in their upper part. The shale units in the Frontier Formation are generally thin bedded, dark gray to black, silty, very carbonaceous with streaks of coal and are interbedded with thin- to massive-bedded, commonly crossbedded, fine-grained to conglomeratic sandstone. Approximately 10 percent of the Frontier Formation at Livingston contains chert pebbles, and according to Hares (1916, p. 246), Knappen and Moulton (1931, p. 33), Thom, Hall, Wegemann, and Moulton (1935, p. 49), Cobban and Reeside (1952a, p. 1960), Hose (1955, p. 54), Richards (1955, p. 49; 1957, p. 416), Van Houten (1962, p. 225), and many others, chert pebbles are typical of the Frontier Formation.

AGE AND CORRELATION

The lower half of the type Frontier Formation in southwestern Wyoming has not been precisely dated, but it is probably Cenomanian according to Cobban and Reeside (1952a, p. 1913). They dated the top of the formation at its type area as early Niobrara (Coniacian) age. In their regional study of the Frontier, Cobban and Reeside (1952a, p. 1958–1959) demonstrated that the upper part of the formation is progressively older from west to east across Wyoming. The upper beds range in age from early Niobrara at the type locality in southwestern Wyoming to late Carlile and Greenhorn ages in central Wyoming.

The Frontier Formation in the Livingston area contains a few poorly preserved specimens of *Inoceramus* sp. and many casts of *Ophiomorpha* and other animal burrowings preserved as sand-filled tubes of a size similar to those of *Ophiomorpha*, but parallel to the bedding surfaces (fig. 10). In a roadcut along U.S. Highway 10 just south of Livingston, Mont. in the SW¼ sec. 19, T. 2 S., R. 10 E. (USGS Paleobotany loc. D–1785) a sample collected from the Frontier Formation yielded corroded palynomorphs unidentifiable as to species. The fauna, identified by R. H. Tschudy (written commun., 1962) included the following:

Tricolpate pollen	Trilete fern spores
Triporate pollen	*Cicatricosisporites*
Monosulcate pollen	Monolete fern spores
Taxodiaceous pollen	Hystrichospheres
Classopollis	Dinoflagellates
Eucommiidites?	*Pterospermopsis*
Bisaccate pollen	

The presence of the triporate pollen supports the assignment of these rocks to the post-Albian Cretaceous. The marine organisms—hystrichospheres and dinoflagellates—are evidence for marine, or at least brackish-water, deposition. Specimens of *Ophiomorpha* (*Halymenites*) (Häntzschel, 1962, p. W251) in Cretaceous sandstones have been interpreted (Brown, 1939, p. 254) as being the burrows of a decapod crustacean that lived in littoral or shallow neritic sandy environments similar to those inhabited by the modern crustacean *Callianassa major* Say (Weimer and Hoyt, 1964).

Bowen (1918, p. 196–197) named a sandstone unit exposed in the northern part of the Crazy Mountains basin the Big Elk Sandstone Member of the Colorado Shale. According to Bowen, the Big Elk Sandstone is 248 feet thick and in the approximate stratigraphic position of the Frontier Formation. Near the type section in the Big Elk dome, southwest of Harlowton, Mont. (pl. 3), Reeside and Cobban (1960, p. 37) collected *Neogastroplites maclearni* (index fossil for upper faunal zone of the Albian Stage) from the Mowry Shale 30 feet beneath the Big Elk Sandstone Member. Their fossil identification supports Bowen's tentative correlation of the Big Elk Sandstone with the Frontier; however, most succeeding workers have overlooked Bowen's correlation.

East of the Livingston area, near McLeod, Mont., siliceous shale occurs above the Boulder River Sandstone Member; this relation led Richards (1957, p. 415) to suggest that the Boulder River Sandstone may be partly late Albian in age, the same as the upper part of the Mowry. Cobban and Reeside (1952a, p. 1961) use similar reasoning for suggesting that the Big Elk Sandstone may be of Albian age.

It is the opinion of this writer that the Boulder River Sandstone and overlying sandy sequence at McLeod (Richards, 1957, p. 416) is correlative with the Big Elk Sandstone and that both are lithogenetic equivalents of the Frontier Formation as recognized in adjacent areas (fig. 2). The Frontier Formation is older in the Livingston-Shawmut area than it is farther east because of the gradual withdrawal of the sea to the east.

Sandstone in the upper part of the Frontier Formation at Livingston grades eastward in southern Montana to shale. Young (1951, p. 36–37) proposed to redefine the Frontier south of Hardin, Mont., to include the shale; however, in that area the shale facies was assigned by Thom, Hall, Wegemann, and Moulton (1935, p. 49) to the Carlile Shale and by Richards (1955, p. 49) to the lower member of the Cody Shale.

West of Hardin, near Bridger, Mont., the Peay Sandstone Member of the Frontier Formation of Knappen and Moulton (1931, p. 32–33) is probably correlative with part of the Boulder River Sandstone Member. The Torchlight Sandstone Member of the Frontier of Knappen and Moulton (1931, p. 32–33) is probably correlative with the upper part of the Frontier Formation at Livingston. These correlations are based on uniformity of lithology and thickness of the Frontier and on the presence in both areas of the underlying Mowry Shale and the overlying Cody Shale.

CODY SHALE

In the Livingston area the Cody Shale is a nonresistant sequence between the Frontier and Telegraph Creek Formations. The Cody forms grassy slopes and valleys along the flanks of the major folds in the area. Exposures are generally weathered and discontinuous.

The Cody Shale was named by Lupton (1916, p. 171) for 3,360 feet of shale and sandy shale between the Frontier and Mesaverde Formations near Basin, Wyo. Lupton (1916, p. 171) also referred to the Cody as being similar to a lithologic sequence, 2,150 feet thick, that Hewett (1914, p. 98) briefly described along the Shoshone River at Cody, Wyo. Fox (1939, p. 5) later redescribed Hewett's section along the Shoshone River 2 miles east of Cody and urged that it be accepted as the standard section of the Cody Shale because of its location at the town for which it was named and because of its completeness of exposure and its completeness of microfauna, including arenaceous forms of a western sandy facies and calcareous forms of an eastern shaley facies. Fox's (1939, p. 18–22) section is now generally accepted as the standard section by most stratigraphers.

Iddings and Weed (1894) mapped a unit, the Montana Formation, in the Livingston area, which probably includes the Cody Shale and Telegraph Creek Formation of this report. They correlated their Montana Formation with the Fox Hills Sandstone and the Pierre Shale (Iddings and Weed, 1894, p. 2).

The Cody Shale, which conformably overlies the Frontier Formation in the Livingston area, represents a transgressive return to deeper water marine conditions, with the shoreline to the west. The Cody in this area is subdivided into a lower shale member, a middle sandstone member named the Eldridge Creek Member, and an upper shale member (Roberts, 1965, p. B59). The Cody Shale ranges in thickness from 1,285 to 1,375 feet. The Eldridge Creek Member, named by Roberts (1964c) is a tongue of shallow-water marine sandstone in the middle part of the Cody Shale; it represents a temporary regression of the Cretaceous sea during middle Niobrara time. The type section of the Eldridge Creek is located near the abandoned townsite of Cokedale along Eldridge Creek in the NE¼ sec. 27, T. 2 S., R. 8 E. Eldridge Creek was named for George H. Eldridge, the outstanding pioneer geologist who first studied the coal deposits of this area.

LITHOLOGIC COMPOSITION

In the Livingston area, the Cody Shale consists chiefly of nonresistant, dark-brownish-gray, partly silty and sandy, marine shale and contains thin interbeds of bentonite and sandstone (refer to measured section 11). Shale constitutes most of the lower part; sandstone, the middle part; and shale, siltstone, and sandstone, the upper part.

The lower member, which overlies the Frontier Formation with apparent conformity, is 400 to 590 feet thick and is dark-gray to dark-brown marine shale interbedded with siltstone throughout.

The Eldridge Creek Member is a persistent unit of thin-bedded greenish-gray fine-grained sandstone (fig. 11). This member is very glauconitic and widespread in southwestern Montana, and for these reasons it is an excellent marker bed. In the Livingston area the Eldridge Creek Member ranges in thickness from 90 to 120 feet.

Conformably overlying the Eldridge Creek Member is the upper shale member, which consists of 500 to 845 feet of dark-gray to brown marine shale and siltstone interbedded with very fine grained sandstone. The proportion of sandstone gradually increases toward the top of the member, and the member appears to be conformably and gradationally overlain by siltstone and sandstone of the Telegraph Creek Formation.

The Cody Shale is commonly pyritic and glauconitic, and in the lower shale member there is a persistent zone of calcareous shale (fig. 2). The sandstone is generally greenish gray, thin bedded, silty, glauconitic, and very fine grained (table 1). It is composed mostly of subrounded grains of quartz and contains lesser amounts of glauconite, mica (generally biotite), lithic chert, and a heavy-mineral suite that is dominantly magnetite.

Thickness of the Cody Shale or its stratigraphic equivalents is generally uniform in much of western Montana and northwestern Wyoming. It is 1,285 feet thick at Livingston; 1,272 feet thick at Mount Everts in Yellowstone Park (Fox, 1939, p. 25); 1,320 feet thick just west of the Pryor Mountains at Wade, Mont. (Fox, 1939, p. 29); and 900–1,200 feet thick in the Great Falls, Mont., area (Cobban and others, 1959, p. 2793). The Cody thickens markedly to the southeast into the Bighorn Basin, where it is 2,120 feet thick at Cody (Fox, 1939, p. 19) and 3,360 feet thick at Basin, Wyo. (Lupton, 1916, p. 171). Similarly, the Cody increases in thickness from 3,600 feet in the northwestern part of the Wind River Basin to more than 5,000 feet in the southeastern part (Keefer and Rich, 1957, p. 72).

FIGURE 11.—Thin-bedded glauconitic very fine grained sandstone of the Eldridge Creek Member of the Cody Shale in the SE¼ sec. 27, T. 2 S., R. 9 E.

AGE AND CORRELATION

The lower shale member of the Cody Shale is correlative with the Greenhorn Formation, Carlile Shale, and the lower part of the Niobrara Formation of northeastern Wyoming (fig. 2). A persistent limy shale unit or calcareous zone in the lower part of the lower shale member is correlative with the Greenhorn Calcareous Member of the Cody Shale of south-central Montana and the Cone Calcareous Member of the Marias River Shale of northwestern Montana.

A marine fauna was first collected from the Eldridge Creek Member of the Cody Shale near Livingston by W. M. Davis and identified by R. P. Whitfield (in Eldridge, 1886, p. 747). Whitfield classed the fauna as characteristic of the Fort Benton and Niobrara faunal divisions of the Colorado Group.

The Eldridge Creek Member in the Livingston area contains the following fauna identified by W. A. Cobban (written commun., 1955):

USGS Mesozoic locality no. D581 (in the SE¼ sec. 27, T. 2 S., R. 9 E.):
- Pelecypods:
  - *Pinna* sp.
  - *Inoceramus* cf. *I. involutus* Sowerby
    - cf. *I. stantoni* Sokolow
  - *Ostrea congesta* Conrad
  - *Gryphaea* sp.
  - *Exogyra* sp.
  - *Anomia subquadrata* Stanton
- Gastropods:
  - *Gyrodes depressa* Meek
  - *Turritella* sp.
  - *Actaeon propinquus* Stanton
- Cephalopods:
  - *Baculites asper* Morton
  - *Scaphites* sp.
  - *Actinocamax* n. sp.

USGS Mesozoic locality D1779 (in sec. 14, T. 3 S., R. 7 E.):
- Pelecypods:
  - *Inoceramus* cf. *I. involutus* Sowerby
    - cf. *I. stantoni* Sokolow
  - *Pteria* sp.
  - *Ostrea congesta* Conrad
  - *Anomia subquadrata* Stanton
  - *Pholadomya papyracea* Meek and Hayden
  - *Crassatella* sp.
  - *Legumen* sp.
  - *Panope* sp.
- Gastropod:
  - *Gyrodes depressa* Meek

USGS Mesozoic locality D2592 (in sec. 26, T. 3 S., R. 7 E.):
- Pelecypods:
  - *Pinna* sp.
  - *Inoceramus* cf. *I. involutus* Sowerby
  - *Pteria* cf. *P. linguaeformis* (Evans and Shumard)
  - *Ostrea congesta* Conrad
  - *Exogyra* sp.
  - *Anomia subquadrata* Stanton
  - *Crassatella andrewsi* Henderson
- Gastropods:
  - *Gyrodes conradi* Meek
  - *Turritella* sp.
- Cephalopods:
  - *Baculites asper* Morton
  - *Scaphites* cf. *S. depressus* Reeside
    - cf. *S. binneyi* Reeside

According to W. A. Cobban (written commun., 1955) the fauna is similar to that from the lower part of the Smoky Hill Chalk Member of the Niobrara Formation. The diagnostic short-ranging ammonite, *Scaphites depressus*, places the Eldridge Creek Member in a limited part of the upper Coniacian (fig. 2). Cobban further commented that the fragmentary condition of the fossils and presence of abundant oysters suggested a shallow-water near-shore marine environment of normal salinity.

W. A. Cobban (written commun., 1957) identified the following fauna collected by G. S. Garbarini from the Eldridge Creek Member near McLeod, Mont., east of Livingston.

USGS Mesozoic locality D1282 (in sec. 8, T. 3 S., R. 13 E.):
- Pelecypods:
  - *Nucula* cf. *N. coloradoensis* Stanton
  - *Inoceramus involutus* Sowerby
  - *Pteria* cf. *P. linguaeformis* (Evans and Shumard)
  - *Exogyra* sp.
  - *Pholadomya papyracea* Meek and Hayden
  - *Crassatella* cf. *C. wyomingensis* Sidwell
- Gastropods:
  - *Gyrodes* sp.
  - *Tessarolax hitzii* White
  - *Anisomyon* sp.
- Cephalopods:
  - *Eutrephoceras* sp.
  - *Baculites asper* Morton
    - *codyensis* Reeside
  - *Scaphites tetonensis* Cobban
  - *Actinocamax* sp.

W. A. Cobban (in Richards, 1957, p. 417) collected and identified the following ammonite of late Niobrara (Santonian) age from the upper shale member of the Cody Shale, approximately 120 feet below the Telegraph Creek Formation-Cody Shale contact, near Livingston.

USGS Mesozoic locality 23026 (in sec. 18, T. 2 S., R. 10 E.):
- Cephalopod:
  - *Clioscaphites choteauensis* Cobban

W. A. Cobban (written commun., 1957) identified the following late Niobrara (Santonian) fauna collected by Garbarini (1957, p. 101) from the upper shale member of the Cody Shale, east of Livingston near McLeod, Mont.:

USGS Mesozoic locality D1283 (in sec. 6, T. 3 S., R. 13 E.):
- Brachiopod:
  - *Lingula subspatulata* Hall and Meek
- Pelecypods:
  - *Inoceramus* sp.
  - *Ostrea* sp.
  - *Pholadomya papyracea* Meek and Hayden
- Cephalopods:
  - *Baculites codyensis* Reeside
  - *Clioscaphites vermiformis* (Meek and Hayden)
- Fish scales:
  - *Ichthyodectes* sp.
  - *Echidnocephalus?* sp.

TELEGRAPH CREEK FORMATION

The Telegraph Creek Formation is a shallow-water marine siltstone unit transitional between the underlying Cody Shale and the overlying Virgelle Sandstone Member of the Eagle Sandstone.

The Telegraph Creek Formation was named by Thom (1922, p. 38) for a marine sequence of sandy shale and calcareous sandstone at the head of Telegraph Creek southeast of Billings, Mont. Concretionary sandstone near the middle of the same sequence in the Bighorn Basin, Wyo., was earlier named the Elk Basin Sandstone Member of the Eagle Sandstone by Hares (1917, p. 429), but later (in Bowen, 1918) he assigned the Elk Basin Sandstone Member to the Telegraph Creek Formation.

Knappen and Moulton (1931, p. 35) extended the name of Telegraph Creek to strata west of Billings, near Park City, Mont.; however, according to W. A. Cobban (oral commun., 1968) they used the Elk Basin Sandstone as the base of their formation, and they placed the lower half of the Telegraph Creek of Hares (in Bowen, 1918) in their Niobrara Shale. Richards (1955, p. 57) used the name Telegraph Creek in the type area as a member of the Cody Shale. In the area southeast of Livingston, Richards (1957, p. 417) included equivalent strata in the Colorado Shale.

South of Livingston, Wilson (1934) designated 318 feet of Upper Cretaceous rocks at Gardiner, Mont., as the Telegraph Creek Formation. Near Livingston, Skeels (1939, p. 817) assigned 350 feet of sandy shale and sandstone to the Telegraph Creek(?) Formation. At McLeod, Mont., Garbarini (1957, p. 102) measured 370 feet of Telegraph Creek Formation, including a lower resistant unit 94 feet thick and an upper nonresistant unit 276 feet thick.

Weed (1893, p. 16, 18) referred to the upper 150 feet of the Telegraph Creek Formation at Cokedale, Mont., as the Tombstone Sandstone. At this locality, individual thin platy well-indurated sandstone beds dip 45° into the grassy slopes and weather into forms that resemble rows of tombstones in a cemetery.

The Telegraph Creek Formation consists of thin beds of calcareous sandy siltstone and sandstone and is approximately 275 feet thick at Cokedale, Mont., 9 miles west of Livingston, and 295 feet thick at Livingston (fig. 12).

In the Livingston area the Telegraph Creek Formation is rarely exposed; it generally forms a belt of light-yellowish-gray soil and talus beneath the prominent ridge-forming Virgelle Sandstone Member of the Eagle Sandstone. The formation is usually identified on the basis of lithology and stratigraphic position. The lower and upper contacts of the Telegraph Creek are gradational and are picked arbitrarily in most places. The base of the Telegraph Creek is generally covered by Quaternary deposits; however, in the few localities where it is exposed, the contact with the Cody Shale is placed at the lowermost biotitic sandstone bed (Roberts, 1965, p. B59).

LITHOLOGIC COMPOSITION

In general, the Telegraph Creek Formation consists of thin-bedded light-olive-gray siltstone interbedded with fine-grained to very fine grained light-gray calcareous sandstone and dark-gray mudstone and shale. The formation weathers to a distinctive yellowish gray. At Cokedale (measured section 12), the Telegraph Creek Formation is predominantly siltstone and sandstone at a ratio of approximately 3 to 1. At Livingston the formation (measured section 13) is approximately one-third shale and mudstone and two-thirds siltstone and sandstone. Calcite cements the formation throughout. Sandstones are moderately well sorted and composed of angular to subrounded grains that have a size distribution very similar to that of the upper sandstone member of the Thermopolis Shale (table 1). The sandstones consist predominantly of quartz and contain lesser amounts of potassium feldspar, plagioclase, chert, and some heavier minerals—which (listed approximately in order of decreasing abundance) include magnetite, zircon, tourmaline, biotite, apatite, augite, garnet, and hornblende. The grain size of the sandstone generally increases in coarseness upward from very fine grained or silty in the basal part of the formation to fine grained to medium grained at the top and in the overlying Eagle Sandstone. This transition from very fine grained to medium grained reflects a gradual uplift in the area of the Elkhorn Mountains to the west.

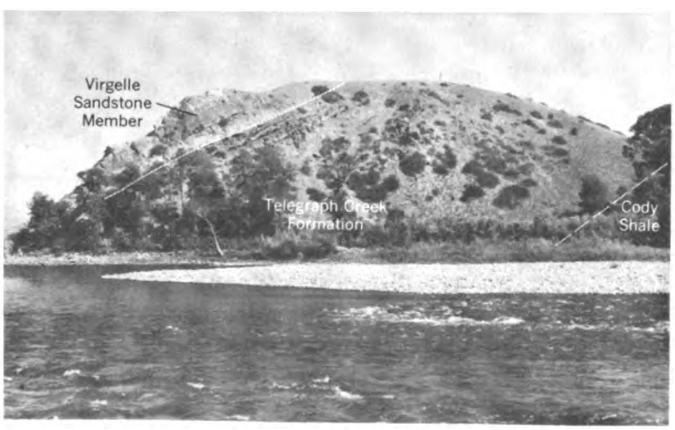


FIGURE 12.—Telegraph Creek Formation immediately east of Livingston, Mont., on the east bank of the Yellowstone River in the NE¼ sec. 18, T. 2 S., R. 10 E. At this locality the Telegraph Creek is a transitional unit between the Cody Shale and the Virgelle Sandstone Member of the Eagle Sandstone.

AGE AND CORRELATION

Thom (1922, p. 38) reported that the fauna from the Telegraph Creek includes species typical of both the Niobrara Shale and the Eagle Sandstone but contains more species of the latter. Reeside (1927) described some cephalopods from the Telegraph Creek and later (in Thom and others, 1935, p. 54–56) listed a more complete fauna from the formation. According to Reeside the Telegraph Creek contains a mixed Eagle and Niobrara fauna; however, he considered the formation to be the basal part of the Montana Group. Cobban and Reeside (1952a) assigned a Santonian age to the Telegraph Creek, and according to their chart the formation forms the base of the Montana Group.

Differences in defining the Telegraph Creek Formation are due partly to the unit's being transitional between the Cody Shale and the Eagle Sandstone. Sandstones designated as the Elk Basin Sandstone Member in the vicinity of the type Telegraph Creek by various authors are not everywhere the same as the type Elk Basin Sandstone near Elk Basin, Wyo. According to W. A. Cobban (oral commun., 1968) the type Elk Basin Sandstone contains *Scaphites hippocrepis*, and a different sandstone identified as Elk Basin by Knappen and Moulton (1931) is older and contains *Desmoscaphites bassleri*. Also, prominent sandstones are known in the Telegraph Creek Formation only in south-central Montana; such marker beds are lacking in the formation in other areas. This problem of defining the Telegraph Creek is further complicated in that the formation becomes older westward and the three units—Cody, Telegraph Creek, and Eagle—become coarser grained in the same direction.

EAGLE SANDSTONE

The Eagle Sandstone near Livingston, Mont., consists of sandstone, siltstone, rock types intermediate between the two, and coal beds.

Rocks deposited in the vicinity of Livingston during the latest part of Cretaceous time and in Paleocene time show a gradual upward transition from the marine Telegraph Creek Formation to the brackish-water marine and nonmarine Eagle Sandstone into continental deposits of the Livingston Group and Fort Union Formation. This sequence is a typical regressive relationship in which coarser near-shore and continental sediments were spread seaward over penecontemporaneously deposited finer grained marine sediments. The regional uplift that produced this regression was accompanied by a little volcanic activity as indicated in the Virgelle Sandstone Member of the Eagle by thin lenticular sandstones derived from andesitic volcanic rocks and near the middle of the Eagle Sandstone by two microlitic tuffs. Volcanic sedimentary rocks make up only a small part of the Eagle, but they are an indication of early volcanic activity to the west, probably in the Elkhorn Mountains near Boulder, Mont.

Weed (1899a, p. 2) named the Eagle Formation from exposures along the Missouri River at the mouth of Eagle Creek in Chouteau County, north-central Montana. At the type locality the formation consists of three lithologic units—an upper unit of light-gray thin-bedded sandstone, a middle coal-bearing unit of siltstone and carbonaceous rocks, and a persistent lower unit of hard massive sandstone. The lower sandstone unit was later named the Virgelle Sandstone Member of the Eagle Sandstone by Bowen (in Stebinger, 1914b, p. 62) from exposures along the Missouri River near the town of Virgelle, Mont. Calvert (1908, p. 108) and Stone (1909, p. 78) first used the name Eagle Sandstone for the coal-bearing sandstone and siltstone sequence in central Montana.

Weed (1893, p. 11) separated the nonvolcanic coal-bearing formation (Eagle Sandstone) from the overlying volcanic-derived sediments of his Livingston Formation (Cokedale Formation of this report) on lithology and stated that the two were separated by an unconformity. Stone and Calvert (1910, p. 761) correctly described Weed's Livingston Formation as conformably overlying the coal measures. Roberts (1957, p. 47; 1963, p. B90) arbitrarily assigned the top of an arkosic sandstone that overlies the uppermost minable coal bed (Cokedale No. 5) as the contact between the Cokedale Formation and the underlying Eagle Sandstone.

In the Livingston area strata of the Eagle Sandstone consist of a sequence of lagoonal, estuarine, deltaic, swamp, and beach deposits. These strata interfinger with marine nearshore and offshore deposits that are mainly to the east and with continental deposits, mainly to the west.

The Eagle Sandstone gradationally overlies the Telegraph Creek Formation and is gradationally overlain by the Cokedale Formation. The lithologic difference between the Eagle Sandstone and the Cokedale Formation is a conspicuous flood of andesitic volcanic detritus in the Cokedale.

Near Livingston the thickness of the Eagle Sandstone ranges from 515 to 860 feet and averages about 600 feet. The Eagle Sandstone is best exposed at Cokedale, 9 miles west of Livingston, where it is 645 feet thick, including the 110-foot-thick Virgelle Sandstone Member at its base (measured section 14).

The Eagle Sandstone is about twice as thick at Cokedale as it is a few miles to the north or east. At Loweth, Mont., the Eagle Sandstone is 470 feet thick and at Columbus, Mont., it is 245 feet thick (J. R. Gill, oral commun., 1962). At the southern end of the Bridger Range the Eagle is about 600 feet thick but thins to about 100 feet thick at the northern end of the range (McMannis, 1955, p. 1388, 1407). Thickness of the Eagle Sandstone increases southward from Livingston, and at Mount Everts near Gardiner, Mont., it is 777 feet thick (Fraser and others, 1969, p. 106). West of the Livingston area the Eagle has been truncated (Robinson, 1963, p. 58). Varying thicknesses among localities is due to an eastward depositional thinning and to differences among workers in placement of the formation contacts. In north and south-central Montana the Eagle is overlain by marine shale and interbedded sandstone of the Claggett Shale. In areas where the Claggett is present, the top of the Eagle Sandstone is the uppermost nonmarine bed; however, in areas where the Claggett equivalent is nonmarine, the top of the Eagle is generally placed at the lithologic change where volcanic detritus becomes abundant. In some areas near Livingston, coal-bearing rocks in the lower part of the nonmarine Claggett equivalent lie conformably on coal-bearing rocks of the Eagle, making separation of the two formations difficult.

LITHOLOGIC COMPOSITION

The Eagle Sandstone at Cokedale consists generally of well-bedded to massive, well-indurated, crossbedded sandstone intercalated with beds of coal, carbonaceous siltstone and shale, and tuff or tuffaceous siltstone (measured section 14). All gradations between sandstone and siltstone are found, but sandstone beds predominate. The sandstone is very light gray to yellowish gray and of variable composition and texture—in some localities, massive and coarse grained; in others, banded or laminated and fine grained.

The upper part of the Eagle Sandstone includes an upper carbonaceous unit and a lower sandstone unit (fig. 13). The carbonaceous unit, or upper coal zone, consists of coal beds, carbonaceous siltstones, and sandstones. The lower sandstone unit consists of well-bedded to massive, medium- to well-sorted, light-olive-gray, quartzose sandstone and siltstone. The indurated beds are generally calcareous. A mechanical analysis of a representative sandstone sample is shown in table 1. Sand grains are angular to subangular and have the following distribution: 38.9 percent fine sand, 51.0 percent very fine sand, and 10.1 percent silt and clay. The sample is 33.4 percent carbonate by weight and has a distinctive heavy-mineral suite. The heavy minerals (listed approximately in order of decreasing abundance) are magnetite, zircon, tourmaline, augite, rutile, staurolite, apatite, anatase, muscovite, biotite, corundum (colorless), epidote, and garnet (colorless).

The lower half of the Eagle Sandstone contains two carbonaceous units alternating with two sandstone units. The lowest sandstone unit is the Virgelle Sandstone Member. Above it are the two carbonaceous units and an intervening sandstone unit which constitute the lower coal zone. The carbonaceous units consists of coal, carbonaceous siltstone, and fine-grained sandstone. The medial sandstone unit is hard, massive, light gray, fine grained, calcareous, and quartzose and contains a variety of heavy minerals. Oysters, *Inoceramus*, and large plant fragments are present in the middle of this unit. This medial sandstone unit lenses out along its strike and is not present east of sec. 26, T. 2 S., R. 8 E., or west of sec. 21, T. 2 S., R. 8 E. A representative sample from lower in the Eagle contains angular to subrounded grains in the following distribution: trace of coarse sand, 11.2 percent medium sand, 61.3 percent fine sand, 17.5 percent very fine sand, and 10.0 percent silt and clay (table 1). The sample is 15.7 percent carbonate by weight. The heavy minerals (listed approximately in order of decreasing abundance) are magnetite, zircon, tourmaline, garnet (colorless), brookite, rutile, apatite, staurolite, epidote, muscovite, biotite, and corundum (colorless).

The two coal zones in the formation, above the Virgelle Sandstone Member, are persistent throughout the area (Roberts, 1957, p. 43) and contain many commercial-grade coal beds (Roberts, 1957; 1966, p. A24–A29). The coals are high-volatile A, B, and C bituminous in rank, some of coking quality. The estimated coal reserves remaining in the Eagle Sandstone in the Livingston coal field, as of January 1965, totaled more than 300 million short tons (Roberts, 1966, p. A49–A51). These reserves are in beds 14 inches or more thick and within 3,000 feet of the surface.

The Virgelle Sandstone Member is firmly cemented, massive to crossbedded, very light gray, generally fine grained quartzose sandstone. It contains a few channel-fill pebble-conglomerate zones, and near its center a few lenticular beds contain fragments of microporphyritic and fine-grained andesite. Locally the uppermost beds of the Virgelle contain 1 percent or more magnetite. The magnetite and other heavy minerals were concentrated in a beach environment during regression of the sea. A mechanical analysis of the insoluble residue of a representative sample from the middle of the Virgelle indicated that the angular to subrounded (generally subangular) grains have the following Wentworth distribution: 0.08 percent medium sand, 66.67 percent fine sand, 14.96 percent very fine sand, and 18.26 percent silt and clay (table 1). The sample is 23.75 percent carbonate by weight. Heavy minerals in the sample (listed approximately in order of decreasing abundance) are magnetite, zircon, tourmaline, muscovite, biotite (green and brown), apatite, diopside, corundum (colorless and red), rutile, staurolite, garnet (pink), hornblende (green), and epidote(?).

Petrographic examination of the Eagle Sandstone indicates that it consists predominantly of quartz (15–50 percent) and contains lesser amounts of plagioclase (andesine), potassium feldspar (orthoclase), and rock fragments of fine-grained andesite, microlitic and microporphyritic andesite, quartzite, and chert. Most quartz grains have straight to slightly undulose extinction and a few vacuoles and inclusions, which suggest a plutonic source. Some of the quartz grains, however, have strongly undulose extinction and no inclusions or vacuoles, which suggest a metamorphic source. Other minerals present in thin section are hematite, ilmenite, leucoxene, allanite, chlorite, pyrite, sericite, and clay minerals. Carbonaceous material is abundant. Samples from units 38 and 41 in measured section 14 contain greater than 1 percent pyrite.

Secondary carbonate commonly replaces feldspar and makes it difficult to distinguish between rock fragments and matrix. Carbonate is present as a cement, and silica and zeolite minerals are present in the cement in trace amounts.

Tuffs in the Eagle Sandstone generally consist of a fine-grained matrix or groundmass that contains abundant plagioclase microlites and laths. Numerous cavities are present which are filled with carbonate and silica. Many siltstones in the upper part of the formation contain enough volcanic ash or very fine grained volcanic debris to be termed tuffaceous (measured section 14).

AGE AND CORRELATION

Fossil leaves collected by members of the Northern Transcontinental Survey from beds presumably in the lower part of the Livingston Group were described by

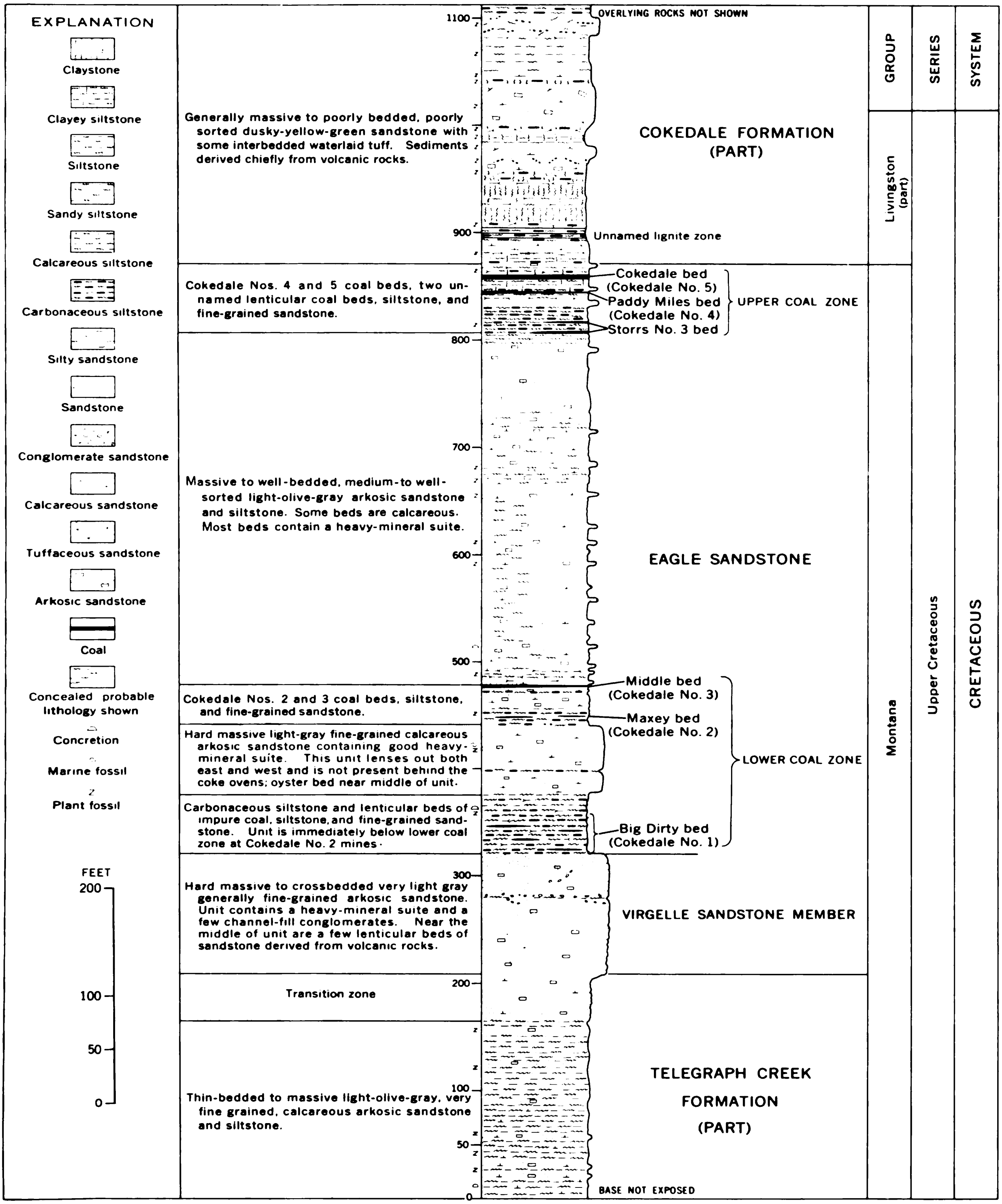


FIGURE 13.—Stratigraphic reference section of the Eagle Sandstone in the NW¼ sec. 26, T. 2 S., R. 8 E., at Cokedale, Park County, Mont.

Lesquereux (1873, p. 404–417) and assigned to the early Eocene. Knowlton (1892, p. 153–154) examined this and subsequent collections from other localities in this area, including some collections from the Eagle Sandstone, and designated the entire collection as the fossil flora of the Bozeman coal field of Laramie age. According to Pumpelly (1886, p. 692) the coal-bearing horizon at the Bozeman coal field was "about 3,700 feet above the Jurassic and some distance above fossils of Benton or Niobrara age and yet so low in the Cretaceous column as to be apparently below the Laramie." Davis (1886, p. 698) stated, on the basis of paleontological studies by R. P. Whitfield, that "the horizon of workable coals near the Muir tunnel (Bozeman Pass—5 miles west of Cokedale) is without question lower than the Laramie Formation to which the lignitic coals of the Rocky Mountain region have generally been referred." However, Weed (1893, p. 18) again assigned the coal-bearing formation at Livingston, Mont., to the Laramie Formation, partly on the basis of Knowlton's work and partly on the conformable relation with underlying rocks (Telegraph Creek Formation) believed to be of Montana age. The basal massive sandstone (Virgelle Sandstone Member of the Eagle Sandstone) was assigned by Weed (1893, p. 19) to the Fox Hills Sandstone. The Laramie Formation, according to Weed (1893, p. 34), was overlain unconformably by his Livingston Formation. Stanton (in Stone and Calvert, 1910, p. 659–660) identified marine fossils of early Montana age from beds at the base of the coal-bearing formation east of the Bridger Range and correlated the formation with the Eagle Sandstone in the northern part of the Crazy Mountains basin as established there by Stone (1909, p. 78).

The first comprehensive study of a megafauna from the Eagle Sandstone and related formations in the western interior of the United States was made by Reeside (1927). Strata north of Livingston that contain a marine fauna were assigned to the lower part of the Montana Group of the Upper Cretaceous (Reeside, 1927, p. 1).

At Cokedale the Eagle Sandstone contains a few sporadic poorly preserved *Inoceramus* sp. and *Ostrea* sp. To the north in the SE¼ sec. 24, T. 4 N., R. 7 E., J. R. Gill and the author collected *Inoceramus* sp., *Ostrea* sp., *Crassatella* sp., and *Tellina* sp. from the Eagle Sandstone. G. D. Fraser (written commun., 1961) collected the following fossils, which were identified by W. A. Cobban, from the upper part of the Eagle near Gardiner, Mont., 0.9 mile east-southeast of the mouth of the Gardner River on the south bank of the Yellowstone River: *Inoceramus* sp., *Crassostrea* cf. *C. soleniscus* (Meek), *Anomia* sp., *Ostrea coalvillensis* Meek, and *Cymbophora arenaria* (Meek). According to W. A. Cobban (written commun., 1961), this fauna indicates that the top of the Eagle Sandstone at Gardiner is no younger than the lower part of the Eagle of central Montana and that an even older age is possible (fig. 2).

Near the middle of the Eagle Sandstone at USGS Paleobotany locality D4121 (refer to measured section 14, unit 37), R. H. Tschudy (written commun., 1969) identified the following palynomorphs from a sample of the Cokedale No. 3 coal bed:

Gleicheniidites	*Eucommiidites*
Ephedra 10B	*Polypodiacidites*
Microfoveolatisporis	*Stereisporites*
Anemia	and the code species:
Inaperturopollenites	C_3–r 10
Proteacidites	CP_3–fov 2
Appendicisporites	Pa_3–sm 10B

Most of these are long-ranging forms. *Ephedra* 10B and CP_3 –fov 2 are the only forms present that are limited to the Eagle Sandstone.

LIVINGSTON GROUP

The name Livingston Formation was first applied by Weed (1893, p. 21) to the thick sequence of sedimentary rocks that consist chiefly of debris of andesitic lava and other volcanic rocks "typically developed in the vicinity of Livingston, Mont." (fig. 14). He divided the formation into three units—the leaf beds (lowest), the volcanic agglomerates, and the conglomerates. The volcanic agglomerate unit occurs only locally, 35 miles east of Livingston (Ross and others, 1955; fig. 14), and its stratigraphic position is uncertain. For a discussion of this unit the reader is referred to Vhay (1934, p. 57–71), Parsons (1942), and Garbarini (1957, p. 113–117). Vhay (1934, p. 66–71) concluded that the agglomerate unit is a series of mudflows that have modified pyroclastic ejecta. Peale (1896) extended the name Livingston westward to include predominantly pyroclastic deposits in Jefferson Canyon, southwest of Three Forks, Mont.; near Sphinx Mountain in the Madison Range; and in the Maudlow area at the north end of the Bridger Range (Peale, in Weed, 1893, p. 21). Iddings and Weed (1894) and Weed (1899b) assigned strata younger than the Eagle Sandstone in most of the Crazy Mountains basin to the Livingston Formation. Coal-bearing rocks in the northern part of the basin were first correlated with the Eagle Sandstone of Cretaceous age by Stone (1909, p. 78–79); however, he placed the Livingston in the Tertiary. Two years later, Stone and Calvert (1910, p. 551) demonstrated that the Livingston Formation grades laterally northeastward into marine and nonmarine beds of the Claggett, Judith River, Bearpaw, Lennep, and Lance (Hell Creek) Formations of Late

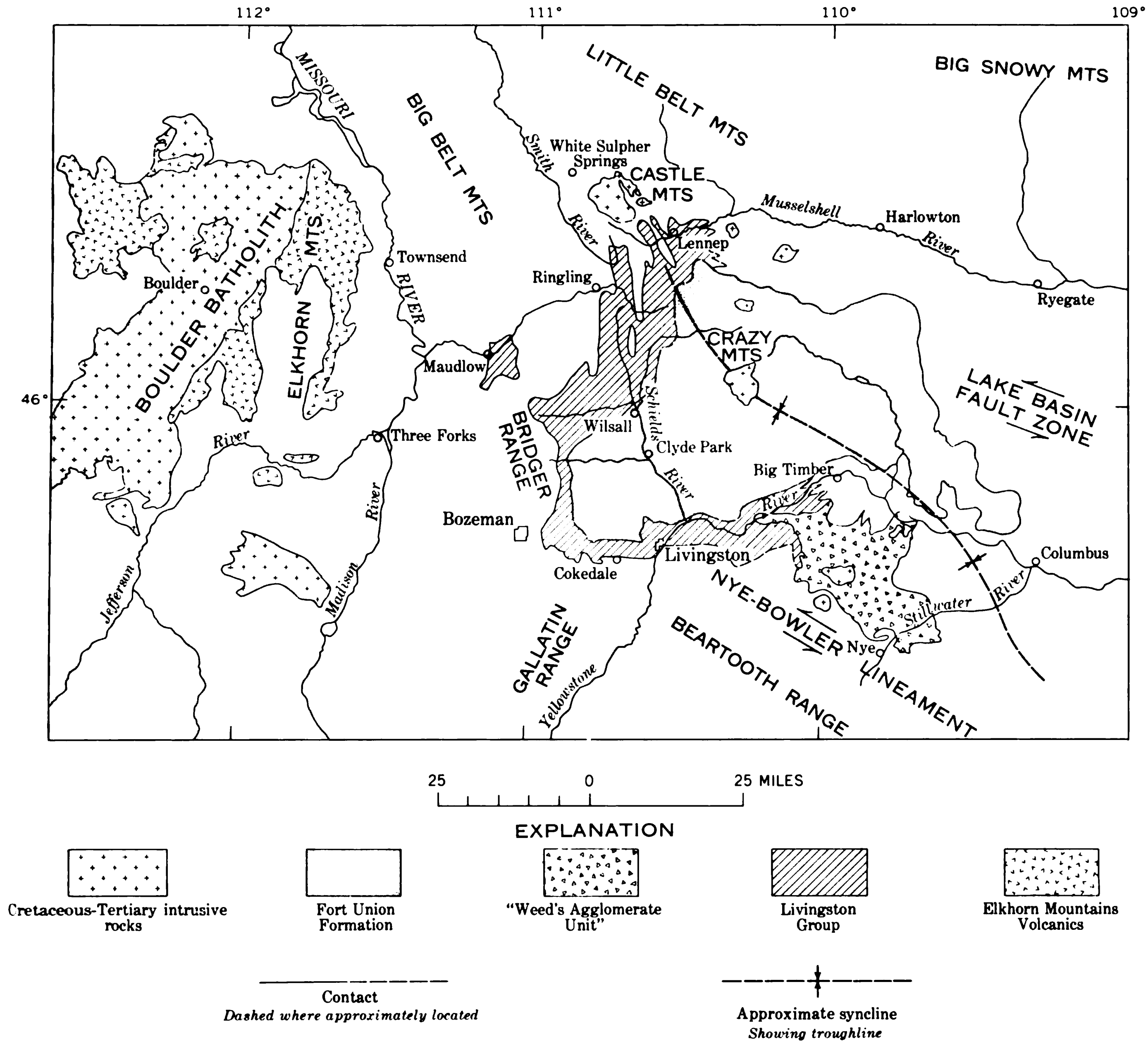


FIGURE 14.—Distribution of the Livingston Group in relation to the Crazy Mountains depositional basin and the Elkhorn Mountains source area in southwestern Montana.

Cretaceous age and the Lebo Andesitic Member of the Fort Union Formation of Paleocene age. Transgressive and regressive relations of these stratigraphic units were described by Stebinger (1914b, p. 67). No further stratigraphic studies of the Livingston were made in the southwestern part of the basin until McMannis (1955, p. 1407) and Richards (1957, p. 420) divided the formation into five generalized lithologic units, including the Fort Union Formation. Roberts (1963) named these units, raised the term Livingston to group rank, and excluded the Fort Union Formation.

Weed (1893, p. 18) assigned the coal-bearing formation (Eagle Sandstone) at Livingston, Mont., to the Laramie Formation, partly on the basis of Knowlton's work (1892, p. 153–154) and partly on the conformable relation with underlying rocks (Telegraph Creek Formation) believed to be of Montana age. The basal massive sandstone (Virgelle Sandstone Member of the Eagle Sandstone) was assigned by Weed (1893, p. 19) to the Fox Hills Sandstone. The Laramie Formation, according to Weed (1893, p. 34), was overlain unconformably by his Livingston Formation. Stanton (in

Stone and Calvert, 1910, p. 659–660) identified marine fossils of early Montana age from beds at the base of the coal-bearing formation east of the Bridger Range and correlated the formation with the Eagle Sandstone established by Stone (1909, p. 78) in the northern part of the Crazy Mountains basin.

Stone and Calvert (1910, p. 551) correlated Weed's Livingston Formation (1893, p. 21) as a "shore phase" of the Claggett Shale, Judith River Formation, Bearpaw Shale, Lennep Sandstone, Lance Formation, and Lebo Andesitic Member of the Fort Union Formation. Roberts (1963) subdivided this sequence of nonmarine sedimentary rocks into five formations, the lower four being restricted to the Livingston Group and the upper formation being assigned to the Fort Union Formation. The Livingston Group, as restricted by Roberts (1963), includes (in ascending order) the Cokedale, Miner Creek, Billman Creek, and Hoppers Formations. The correlation and stratigraphic relations of the type Livingston Group near Livingston, Mont., with rocks in other areas in Montana and Wyoming are shown in figure 2. Stratigraphic assignments of these nonmarine formations were aided by comparing pollen and spore assemblages. These microfossils were identified by E. B. Leopold and R. H. Tschudy and are listed in table 4.

The Cokedale Formation is a nonmarine unit composed largely of siltstone and sandstone and lesser amounts of mudstone, tuff, bentonite, and lignite which occur mostly in the lower part. The Cokedale rests conformably on the Eagle Sandstone and correlates in central Montana with the Claggett Shale, Judith River Formation, and Bearpaw Shale and in northwestern Montana with part of the Two Medicine Formation. The Miner Creek Formation conformably overlies the Cokedale and consists largely of alternating beds of nonmarine siltstone and sandstone including a prominent ridge-forming unit, the Sulphur Flats Sandstone Member, at the base. The Miner Creek correlates eastward with the lower part of the Hell Creek Formation, and the Sulphur Flats Sandstone Member is probably the nonmarine facies of the marine Lennep Sandstone and Horsethief Sandstone to the north. The overlying Billman Creek Formation is a nonmarine sequence of red, purple, and green mudstone intercalated with a few beds of tuff, bentonite, and sandstone. The Billman Creek rests conformably on the Miner Creek Formation and correlates northward and eastward with the middle part of the Hell Creek Formation. The upper part contains the same pollen and spores as the type Colgate Member of the Fox Hills Sandstone at Glendive, Mont. The overlying Hoppers Formation, also nonmarine, is a sequence of sandstone and conglomerate interbedded with some siltstone, mudstone, and tuff. The Hoppers correlates northward and eastward with the upper part of the Hell Creek Formation.

The Livingston Group at Cokedale, Mont. (pl. 2), is a thick alternating series of coarse- and fine-grained continental deposits that have rapid vertical and lateral variations in lithology. The Livingston rocks probably represent fluvial channel systems and extensive flood-plain deposits near sea level as indicated by their similarities to Holocene deposits that have these origins. The strata are characterized by poor sorting; angularity of grains; crossbedding; thick sequences in which mudstone and sandstone alternate; mudstone-pebble conglomerates; oxidized zones; and the presence of freshwater gastropods and pelecypods, fragments of dinosaur bones, and wood and leaf debris. The continental sequence of the Livingston Group at Cokesdale could be the result of large variations in the quantity of sediment deposited in the rapidly subsiding western part of the Crazy Mountains basin. Changes from coarse- to fine-grained clastic rocks may represent fluctuations in supply of sediment along the basin margin that resulted from periodic uplift in slightly different locales, changes in elevation by volcanic eruptions, and the extrusion of volcanic rocks of different susceptibility to erosion in the source area. Renewed erosional activity resulting from any of these conditions, and (or) renewed downwarping of the basin, periodically caused the coarser grained sediment to spread farther basinward across finer grained offshore marine sediments. Conversely, a decrease in the amount of erosion from the source areas, and (or) uplift of the basin, periodically permitted the finer grained offshore marine sediments to transgress westward across the coarse-grained nearshore deposits.

Many sandstone units within the Livingston Group are conglomeratic. The cobbles and pebbles of these units consist mainly of various kinds of andesitic volcanic rock. Certain heavy minerals—such as sillimanite, corundum, staurolite, and garnet—in the sandstone units indicate a Precambrian source of lesser importance than the volcanic source; however, lithic fragments of Precambrian rock are not present, suggesting very little exposure or uplift of Precambrian rocks in the source area in comparison with the andesitic volcanic rocks. Some conglomeratic sandstones contain coarse sand to pebble-sized tabular fragments of mudstone in scour-and-fill structures. The edges of these fragments are generally rounded, which indicates a short distance of transport. These coarse-grained clastic deposits thin eastward.

TABLE 4.—*Checklist of plant and miscellaneous microfossils from the type Livingston Group and the Fort Union Formation near Livingston, Mont.*

[Identifications by E. B. Leopold and R. H. Tschudy. Numbers preceded by D indicate USGS Paleobotany localities]

		Upper Cretaceous							Paleocene		
		Livingston Group							Fort Union Formation (Measured section 20)		
Provisional palynomorph genera	Code species	Cokedale Formation (Measured section 16)			Miner Creek Formation (Measured section 17)		Billman Creek Formation (Measured section 18)		Basal member (upper)	Middle member (lower)	
		Lower		Middle	Lower	Upper	Middle	Upper			
		D1610	D1611	D1815–1 and D4120	D1612	D1613	D1614	D4104A	D1782 and D4105	D1783	D1784
?	TO–sm3	×	×		×	×					
Deltoidospora	TT–sm7	×									
?	TC–sm12	×									
Laevigatosporites	M–sm2	×	×	×	×	×	×				
?	O–r6	×			×	×					
cf. *Verrucosisporites*	O–p1	×									
Abietineaepollenites	V$_2$S–sm3	×			×		×				
Monosulcites	S$_1$–sm4	×	×								
Classopollis	Classo 1	×	×			×			×		
Eucommiidites	C$_3$–sm15	×		×							
Tricolporites	CP$_3$–r8	×			×	×	×				
Cupaneidites	C$_3$–syn–sm1	×							×		
Engelhardtioidites	P$_3$–sm8	×									
Trivestibulopollenites	P$_3$–sm13	×									
Proteacidites	P$_3$–rt6	×	×		×		×		×		
Proteacidites	P$_3$–rt3	×									
?	Pa$_3$–p2	×									
Tricolporites?	C$_3$–sm5		×								
Proteacidites	P$_3$–rt4		×					×			
Triatriopollenites	P$_3$–sm15		×						×		
cf. *Eucommiidites*	C$_3$–sm1B			×		×	×				
Aquilapollenites	Aquila 9			×					×		
Aquilapollenites	Aquila 18			×							
Inaperturopollenites	Tax–sm1			×		×					
Proteacidites	P$_3$–rt1B			×							
Proteacidites	P$_3$–rt3B			×							
?	O–p8			×							
Alnus	Pa$_3$–sm13			×			×				
Tricolpopollenites	C$_3$–r5			×							
Hamulatisporis	TO–rug2			×							
cf. *Verrucosisporites*	TO–p5			×							
Stereisporites	Fmem–sm2			×							
Ephedra	Gn–2			×	×						
Tricolpopollenites	C$_3$–r$_{14}$			×							
Cicatricosisporites	An–1			×					×		
?	O–p$_6$			×							
Polypodiissporites	M–p$_6$			×							
Cicatricosisporites	An–17			×							
Verrucosisporites	TO–p$_{20}$			×							
cf. *Cupaneidites*	CP$_3$–syn–sm$_1$			×							
Stereisporites	Fmem sp			×							
Gleicheniidites	Gleich 2B			×							
Proteacidites	P$_3$–rt 3C			×							
Proteacidites	P$_3$–rt 4B			×							
Tricolporites	CP$_3$–sm			×							
Hemitelia	Hemi–4			×							
?	TO–sp (tetrad)			×							
Cupaneidites	C$_3$–syn–r			×							
Aquilapollenites	Aquila 4 var.?			×							
Aquilapollenites	Aquila 29			×							
Vitreisporites	V$_2$L–sm2			×							
?	O–sp (large)			×							
?	TO–rt			×							
Anemia sp				×							
Abietineaepollenites	V$_2$S–rug 3			×							
Polycolpites	C$_4$–r			×							
Appendicisporites	cf. App–1			×							
Alnus	Pa$_3$–sm 10			×							
Ghoshispora	Charon–1			×					×		
cf. *Acquitriradites*	VOT–sp$_1$				×						
?	TO–sm$_{12}$				×	×					

TABLE 4.—*Checklist of plant and miscellaneous microfossils from the type Livingston Group and the Fort Union Formation near Livingston, Mont.*—Continued

Provisional palynomorph genera	Code species	Upper Cretaceous								Paleocene	
		Livingston Group							Fort Union Formation (Measured section 20)		
		Cokedale Formation (Measured section 16)			Miner Creek Formation (Measured section 17)		Billman Creek Formation (Measured section 18)		Basal member (upper)	Middle member (lower)	
		Lower		Middle	Lower	Upper	Middle	Upper			
		D1610	D1611	D1815-1 and D4120	D1612	D1613	D1614	D4104A	D1782 and D4105	D1783	D1784
Verrucosisporites	TO-p_1				×	×	×				
cf. *Baculatisporites*	TT-p_9				×	×					
cf. *Verrucosisporites*	TO-p_{10}				×						
cf. *Verrucosisporites*	TO-p_{11}				×	×	×				
Cicatricosisporites	An-13				×						
Lycopodiumsporites	TT-rt_6				×						
Cyathidites	TC-sm_3				×	×			×		
?	Fmem-sm_4				×						
Gleicheniidites	Gleich 2				×						×
Laevigatosporites	M-sm_5				×						
cf. *Inaperturopollenites*	O-rt_5				×						
Inaperturopollenites	Tax-p_5				×	×					
?	O-p_9				×	×					
Abietineaepollenites	V_2S-p_2				×						
Micrhystridium	Micr-1				×						
Tricolpopollenites	C_3-r_{20}				×						
Tricolpopollenites	C_3-p_9				×						
Tricolpopollenites	C_3p_{10}				×						
Tricolporites	CP_3-sm_5				×						
?	P_3-p_4				×						
Proteacidites	P_3-rt_1A				×				×		
cf. *Paliurus*	P_3-r_{12}				×						
Aquilapollenites	Aquila 2A				×	×					
Aquilapollenites	Aquila 17				×						
?	TT-sp_9					×					
cf. *Stereisporites*	Fmem-sm_3					×					
?	TT-p_{12}					×					
Verrucosisporites	TO-p_2					×					
Microreticulatisporites	TT-rt_1				×						
Triplanosporites	Tplan-sm_3				×						
cf. *Tricolpopollenites*	C_3-st_1				×						
Tricolporites	CP_3-sm_1				×						
Tricolporites	CP_3-sm_{23}				×						
Tricolporites	CP_3-sm_{24}				×						
Tricolporites	CP_3-sm_{22}				×						
Kurtzipites	C_3-sm_{22}				×					×	
Ulmipollenites	P_3-rug_1				×						
Aquilapollenites	Aquila 19				×						
Aquilapollenites	Aquila 5				×						
Aquilapollenites	Aquila 6				×						
Ericipites	Tet-r_2				×						
Abietineaepollenites	V_2L-sm_6						×				
Tricolporites	CP_3-rtB							×			
Tricolpopollenites	C_3-rt 16B							×			
Proteacidites	P_3-rt 2B							×			
Inaperturopollenites	O-rt 18C							×			
Ulmipollenites	Pa_3-p 4B							×			
Erdtmannipollis	Pperi-p_2							×		×	
Hamulatisporis	TO-rug 22B								×		
Araucariacites									×		
Gleicheniidites	Gleich 4								×		
cf. *Cyathidites*	TT-smlC								×		
Verrucosisporites	TO-p20C								×		
Tricolpopollenites	C_3-rt 36								×		
Schizosporus	S_1-rt4								×		
Lycopodiumsporites	TO-rt 14								×		
Aquilapollenites	Aquila 4E								×		
dinoflagellate	dino								×		×
hystrichosphere	hyst								×		×
Triatriopollenites	P_3-sm_6									×	
Carya?	P_3-$sm_{14}B$?									×	
Tricolpopollenites	C_3-rt_1B									×	
cf. *Betula*	P_3-sm_{34}?									×	

TABLE 4.—*Checklist of plant and miscellaneous microfossils from the type Livingston Group and the Fort Union Formation near Livingston, Mont.*—Continued

Provisional palynomorph genera	Code species	Upper Cretaceous								Paleocene	
		Livingston Group							Fort Union Formation (Measured section 20)		
		Cokedale Formation (Measured section 16)			Miner Creek Formation (Measured section 17)		Billman Creek Formation (Measured section 18)		Basal member (upper)	Middle member (lower)	
		Lower		Middle	Lower	Upper	Middle	Upper			
		D1610	D1611	D1815–1 and D4120	D1612	D1613	D1614	D4104A	D1782 and D4105	D1783	D1784
cf. *Tetrapollis*	P_4–sm_3?									×	------
Erdtmannipollis	Pperi–p_2									×	------
Betula	P_3–sm_{12}									×	------
cf. *Ulmipollenites*	Pa_3–p_4									×	------
Tricolpites	C_3–sm_{19}									×	------
cf. *Tetra pollis*	P_4–sm_6										×
Momipites	P_3–sm_6										×
cf. *Cupaneidites*	C_3syn–r_3										×
Momipites	P_3–sm_1A										×

Crossbedded or cross-laminated strata that are mostly foreset beds are common throughout the coarser clastic units of the Livingston Group, particularly within the sandstone units. Individual foreset beds range in thickness from laminae to beds more than 4 feet thick.

The Livingston Group thins progressively eastward from Livingston toward Columbus, Mont. (Roberts, 1963, p. B87). At Cokedale the sequence is 6,445 feet thick, but it is represented by only 2,750 feet of marine and nonmarine beds near Columbus, Mont. It also thins from Livingston northward to Lennep, Mont., where it includes 4,900 feet of marine and nonmarine beds. The overlying Fort Union Formation likewise thins markedly from Livingston to the east and north. In both directions, rocks of the Livingston and Fort Union become finer grained, better sorted, thinner bedded, lighter in color, and less andesitic in composition (McMannis, 1955) because of an increase in the proportions of quartz and orthoclase. The nonmarine Livingston Group interfingers with marine equivalents in both directions (fig. 2).

In the Livingston type section near Livingston, two prominent tuffaceous zones have regional significance in correlation. A lower tuffaceous zone in the lower part of the Cokedale Formation contains fossils of the *Baculites obtusus* faunal zone, which is found in the basal part of the Claggett Shale at the horizon of the Ardmore Bentonite Bed of the Sharon Springs Member of the Pierre Shale in other parts of Montana and in Wyoming. An upper tuffaceous zone in the lower part of the Miner Creek Formation represents the *Baculites compressus* and *Baculites cuneatus* faunal zones found in the upper part of the Judith River Formation and lower part of the Bearpaw Shale elsewhere in Montana and in Wyoming. The regional stratigraphic significance of bentonitic shale zones at these horizons in the Pierre Shale or its formational equivalents in the northern Great Plains was discussed by Gill and Cobban (1966).

The composition of the volcanic fragments and minerals of volcanic origin in the Livingston Group and Fort Union Formation indicates that they were derived principally from the Elkhorn Mountains volcanic field near Boulder, Mont. (fig. 14). Smedes (1966, p. 21) described the petrology of the Elkhorn Mountains Volcanics as "a lower unit dominantly of andesitic, rhyodacitic, and basaltic pyroclastic and epiclastic volcanic rocks, autobrecciated lavas, and related mudflows. and a few thin partly welded quartz latitic ash flows; a middle unit characterized by sheets of rhyolitic ash flows, most of which now are welded tuff, and intercalated debris similar to that of the lower unit; and an upper unit dominated by bedded and water-laid tuff and andesitic sedimentary rocks."

Lindgren (1886, p. 719) first mapped and examined petrographically the eruptive rocks in and adjacent to the Crazy Mountains basin of which many were source rocks for the Livingston Group and Fort Union Formation. He described many rock types, andesites being the most common. Lindgren (1886, p. 736–737) concluded from his regional study of the eruptive rocks in the Big Belt Mountains that the andesitic eruptions probably began late in the Cretaceous Period or in Laramide time and lasted with different intensity until or after the end of that orogenic period. Later Billingsley (1915, p. 35) examined these rocks and stated that the andesite conglomerate at Maudlow (equivalent to a part of the lower Livingston) (Skipp and Peterson, 1965) could have no other source than the lavas of the Elkhorn Mountains. Berry (1943, p. 22–23), McMannis (1955, p. 1412), and Klepper, Weeks, and Ruppel (1957, p. 40) also concluded that the thick deposits of volcanic material in the Elkhorn Mountains were most likely the source of much of the Livingston.

Several small source areas of much less extent than the Elkhorn Mountains volcanic pile contributed to the sediments near the southern, western, and northwestern margins of the Crazy Mountains basin. A local source near Flathead Pass in the Bridger Range was suggested by Weed (1893, p. 29), and another source area near the Castle Mountains was suggested by Tanner (1949, p. 86). A local source south of Big Timber, Mont., was first described by Weed (1893, p. 26–29) for his "volcanic agglomerates" unit and later by Parsons (1942, p. 1177) for the "Livingston igneous series." In the vicinity of Nye, Mont., volcanic breccias considered to be part of the "Livingston igneous series" by Parsons were derived from small local vents, probably as mudflows (Vhay, 1939, p. 436–437), and are interbedded with the Judith River Formation (Wilson, 1936, p. 1168). The volcanic activity which produced the various rocks assigned to the "Livingston igneous series" probably ceased prior to Hell Creek time (Parsons, 1942, p. 1183).

An eastward increase in abundance of quartz and other minerals of nonvolcanic origin, a decrease in grain size eastward across the Crazy Mountains basin, the presence of volcanic rock known only from the Elkhorn Mountains Volcanics in conglomerate beds of the Livingston Group, and the eastward wedging out of the extrusive units at Maudlow, Mont., corroborate the conclusion of Billingsley, Berry, McMannis, and Klepper that the major volcanic source was to the west and northwest of the basin (fig. 14).

Volcanic material in the Livingston Group includes fragments of several types and textures of andesitic and

TABLE 5.—*Chemical (rapid rock) analyses of very fine grained clastic rocks from the Livingston Group and of comparative samples from the Telegraph Creek Formation and Eagle Sandstone at Cokedale, Mont.*

[Data in percent. Sampled by L. G. Schultz; analyses by L. Artis, S. Botts, G. Chloe, P. Elmore, and H. Smith]

Formation	Billman Creek			Miner Creek		Cokedale		Eagle	Telegraph Creek	
Data system No.	D 0000638	D 0000639	D 0000640	D 0000641	D 0000642	D 0000643	D 0000644	D 0000645	D 0000646	D 0000647
Lab. No.	159822	159823	159824	159825	159826	159827	159828	159829	159830	159831
	1	2	3	4	5	6	7	8	9	10
SiO_2	57.7	57.7	60.0	60.1	59.3	61.1	70.7	57.7	56.1	60.1
Al_2O_3	15.1	15.5	14.3	16.0	16.6	18.0	13.8	11.3	11.2	16.1
Fe_2O_3	5.8	6.0	5.2	5.3	5.3	4.5	2.1	1.8	2.2	5.3
FeO	.54	.47	.60	.36	.62	.47	.85	1.5	.98	.80
MgO	2.7	2.9	3.1	1.3	1.2	.79	1.4	3.5	3.7	1.9
CaO	1.8	2.8	2.2	2.1	2.5	3.7	.58	7.5	8.4	.46
Na_2O	1.0	2.0	1.8	1.2	1.6	3.3	.50	.49	.79	1.2
K_2O	2.5	3.0	2.7	2.2	2.3	1.6	4.1	2.7	2.4	2.4
TiO_2	.64	.59	.57	.55	.53	.56	.53	.45	.45	.66
P_2O_5	.26	.11	.29	.21	.08	.13	.07	.24	.22	.11
MnO	.11	.09	.09	.05	.05	.10	.02	.04	.03	.02
Loss on ignition	11.2	7.9	8.8	10.4	9.9	6.0	5.3	12.2	13.7	10.2
S	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	.00
Acid soluble SO_3	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	.75
Sum	99	99	100	100	100	100	100	99	100	100
H_2O-	6.8	3.7	5.0	6.4	5.7	2.6	1.6	1.3	1.7	4.3
H_2O+	4.7	4.0	4.0	4.1	4.4	3.6	3.6	3.5	3.6	5.4
CO_2	<.05	.20	<.05	<.05	<.05	<.05	.20	7.6	8.5	.12
Powder density by air pycnometer	2.47	2.57	2.52	2.49	2.48	2.59	2.65	2.70	2.70	2.63

*Less than 0.2 percent S as SO_3.

1. Volcanic silty claystone; SE¼SW¼NW¼ sec. 18, T. 2 S., R. 9 E.; 1,800 ft above base of formation.
2. Volcanic siltstone, NE¼SW¼SW¼ sec. 18, T. 2 S., R. 9 E.; 915 ft above base of formation.
3. Volcanic claystone; SE¼NE¼SW¼ sec. 13, T. 2 S., R. 8 E.; 560 ft above base of formation.
4. Volcanic siltstone; NW¼SW¼NW¼ sec. 20, T. 2 S., R. 9 E.; 1,100 ft above base of formation.
5. Volcanic clayey siltstone; NE¼NE¼SE¼ sec. 19, T. 2 S., R. 9 E.; 505 ft above base of formation.
6. Volcanic sandy claystone; SE¼NW¼SW¼ sec. 23, T. 2 S., R. 8 E.; 1,125 ft above base of formation.
7. Clayey siltstone; SE¼SW¼ sec. 24, T. 2 S., R. 8 E.; 315 ft above base of formation.
8. Clayey siltstone; NW¼NE¼NW¼ sec. 26, T. 2 S., R. 8 E.; 200 ft above base of formation.
9. Clayey siltstone; SE¼NW¼NW¼ sec. 26, T. 2 S., R. 8 E.; 200 ft above base of formation.
10. Silty claystone; SE¼NW¼NW¼ sec. 26, T. 2 S., R. 8 E.; 150 ft above base of formation.

possibly some latitic rocks, as well as beds of bentonite and andesitic ash. Samples from very fine grained clastic rocks were chemically analyzed, and the analyses are summarized in table 5. Also present in smaller amounts are lithic fragments of welded tuff, spherulitic and devitrified rocks that may be dacitic in composition, crystal fragments of volcanic and nonvolcanic origin, and clay minerals. The Livingston Group contains a distinct heavy-mineral suite which is summarized together with grain-size distribution in table 6.

The dominant mineral in the heavy-mineral fraction from the Livingston Group, as well as in the overlying Fort Union Formation, is clinopyroxene (table 6). The optical properties of the clinopyroxene mineral place it in the salite-diopsidic augite field, the typical clinopyroxene of intermediate to basic volcanic rocks (R. E. Wilcox, written commun., 1968).

A copper mineral present in most samples from the Livingston Group (table 6) is whitneyite (Fred A. Hilderbrand, oral commun., 1966). This mineral is a copper arsenide and was identified by X-ray analyses. It has some physical characteristics similar to those of gold, such as color and malleableness, that can be misleading; thus detailed examination, such as X-ray or chemical analysis, is required for identification. These characteristics become apparent only after the rock sample has been chemically disaggregated; this process removes the thin oxidized coating on the whitneyite grains. The presence of copper arsenide suggests a probable Precambrian source south of Livingston, such as the Jardine mining district near Gardiner, Mont., because that area is rich in arsenic and related minerals, including native copper (Seager, 1944). Also, the area near Gardiner seems a likely source because beds in the lower part of the Cokedale Formation of the Livingston Group that contain the oldest occurrences of whitneyite are believed to be slightly older than the mineralization of a possible alternate source, the Boulder batholith area of western Montana (fig. 1).

Plagioclase feldspar is the most abundant mineral of probable volcanic origin in the Livingston Group and the Fort Union Formation, after which, in order of decreasing abundance, are diopsidic augite, magnetite, biotite, and hornblende (table 6). The plagioclase ranges from oligoclase to labradorite; andesine is the most common. Potassium feldspar (orthoclase) and quartz are the principal nonvolcanic constituents. The feldspars are generally altered, in part to laumontite and other zeolite minerals, and in part to zoisite, sericite, and clay minerals. With the exception of two atypical quartzose sandstones in the Cokedale Formation and one at the base of the Sulphur Flats Sandstone Member of the Miner Creek Formation, quartz content increases progressively from trace amounts in the lower part of the Livingston to as much as 12 percent in the upper part. Orthoclase content also increases from trace amounts in the lower part to 15 percent in the upper part; this increase suggests a very gradual increase in the size of the source area in which pre-Elkhorn Mountains Volcanics rocks were exposed. Heavy minerals in the Livingston Group, such as sillimanite, corundum, staurolite, and garnet, were derived only from Precambrian metamorphic rocks; however, lithic fragments of these rocks are rare to absent, suggesting that the Precambrian exposures were much farther west or south or were not elevated as high and therefore were less exposed to erosion during deposition of the Livingston Group than later during deposition of the basal conglomeratic member of the Fort Union Formation in which such fragments are present.

Biotite grains in the quartzose sandstones are dark brown and similar to those in the pre-Livingston Group sedimentary rocks; however, biotite in the sandstones that contain volcanic detritus ranges from very light brown to dark brown. Commonly the light-colored variety is difficult to distinguish from muscovite, and the two mica minerals are combined in table 6. Bronze-colored biotite is a characteristic variety in the sandstones of the Miner Creek Formation. The different shades of brown of biotite in the Livingston Group probably represent differences in deuteric or hydrothermal alteration of rocks in the source area.

The finer grained rocks (claystones and mudstones) contain approximately 45 percent montmorillonite and 55 percent mixed-layer montmorillonite-illite-vermiculite; some also have small amounts of illite and chlorite (L. G. Schultz, oral commun., 1962). Kaolinite is generally absent.

Zeolite minerals are common in interstices in the sandstone. Reddish-brown heulandite is the most conspicuous zeolite and is present throughout the Livingston, but it is most abundant in the Miner Creek Formation. Analcime is present in some units as cement, producing a mottled texture because it has crystallized in clusters. Traces of laumontite and clinoptilolite are also present in some units. Other cementing agents are silica, calcite, nontronite, and chloritic minerals.

Stratigraphic sections described in this report extend from the abandoned coal-mining town of Cokedale, Mont., 9 miles west of Livingston, Mont., north to the axis of the Fleshman Creek syncline. Locations of these sections of the type formations in the Livingston Group are shown in figure 15. The total thickness of the Livingston Group is 6,455 feet.

TABLE 6.—*Heavy-mineral content and grain-size distribution in sandstones*

[All data, in percent; indicated diameter,

Stratigraphic name, measured section, and unit sampled	Heavy minerals in the very fine sand fraction (0.088 and 0.062 mm)	Heavy minerals [1]													
		Zircon	Biotite and muscovite [2]	Sphene	Sillimanite	Hypersthene	Corundum	Staurolite	Tourmaline	Epidote	Anatase	Topaz	Garnet	Hornblende	Diopsidic augite
Fort Union Formation:															
Section 20........unit 242..	20.71	7.7	1.2	0.9	0	1.9	0.5	0.4	0	2.1	0	0.2	2.4	0.5	65.1
234..	23.76	5.4	1.4	.6	0	3.2	0	.2	0	.8	0	0	1.4	.8	56.2
147..	5.32	5.7	1.1	2.0	0	2.4	.2	0	.4	1.8	.4	0	5.3	0	72.0
81..	3.72	9.0	1.0	.8	0	3.2	0	0	0	2.2	0	.2	2.4	.3	72.8
35..	5.88	4.9	.5	1.0	0	4.4	0	0	0	.8	0	0	2.9	0	62.3
1..	13.01	7.9	1.0	.9	0	1.5	.6	.2	0	1.5	0	0	.6	1.1	82.4
Livingston Group, Hoppers Formation:															
Section 19.........unit 48..	15.19	8.1	0	1.0	0	1.2	1.0	0	0	1.0	0	0	0	.2	77.9
38..	11.16	6.5	.6	.6	0	1.3	.7	0	0	.9	0	0	.6	.4	79.5
28..	29.79	7.5	1.5	.8	0	1.0	1.0	0	0	.2	0	0	0	.5	83.0
10..	5.62	7.8	2.0	1.4	0	1.8	1.2	.2	0	1.0	0	0	.4	0	64.1
Billman Creek Formation:															
Section 18.......unit 158..	5.88	4.3	.5	2.4	0	2.4	.5	0	0	0	0	0	1.0	.2	70.0
135..	23.94	4.4	.5	1.5	0	3.1	0	0	0	0	0	0	.2	.7	83.7
91..	12.43	5.4	.6	0	0	1.3	0	0	0	0	0	0	1.1	0	84.4
52..	14.48	2.8	.9	0	0	2.1	0	.2	0	.9	0	0	0	.5	81.3
28..	11.07	2.6	.7	0	0	2.6	0	0	0	0	0	0	0	.4	90.8
2..	26.24	3.7	.3	.2	0	.7	0	0	0	.7	0	0	0	.7	83.4
Miner Creek Formation:															
Section 17.......unit 155..	23.72	4.0	0	0	0	1.7	.5	0	0	0	0	0	0	.9	92.4
121..	0.88	5.7	1.1	.7	0	.7	0.7	.2	0	5.3	0	.9	0	8.8	13.4
83..	5.16	1.7	1.0	0	.2	2.9	0	0	0	3.8	0	0	.2	9.1	78.7
78..	0.20	12.9	.8	0	.3	1.4	1.1	.3	.3	1.6	0	1.1	1.4	2.2	7.7
54..	0.07	6.5	2.2	.2	.9	.9	.6	0	0	1.7	0	0	0	0	12.4
47..	0.07	17.4	5.1	0	.2	1.2	2.2	0	.5	0	.2	0	.2	.2	2.9
45..	2.60	7.0	.7	0	0	.7	.7	0	.5	1.0	0	0	0	.5	70.0
Miner Creek Formation, Sulphur Flats Sandstone Member:															
Section 17.........unit 43..	0.49	1.3	.5	0.	31.8	.8	2.2	0	1.3	1.9	0	0	0	3.8	38.9
25..	9.58	4.8	0	0	0	.5	.2	0	.5	.8	0	0	0	0	89.1
1..	0.23	21.7	5.2	1.0	0.2	2.1	1.7	2.6	2.6	6.2	0	.2	24.0	0	21.0
Cokedale Formation:															
Section 16.......unit 159..	9.17	2.6	1.1	0	0	0	0	0	0	2.1	0	0	0	0	93.1
123..	0.26	13.8	3.0	1.1	.7	1.9	0	.4	.4	2.6	2.2	0	.7	0	10.8
93..	0.09	10.3	5.1	.5	1.0	1.5	1.5	4.1	.5	4.1	4.6	0	1.0	.5	4.1
82..	0.12	30.2	14.3	2.5	1.5	12.4	.5	1.5	6.4	9.4	1.5	1.0	1.0	0	5.0

[1] Percent of heavy-mineral fraction of the size fraction (0.088 and 0.062) used for heavy-mineral analysis, percent to nearest 0.1.
[2] Biotite commonly is a very light colored variety and is included with muscovite.

COKEDALE FORMATION

The Cokedale Formation was named by Roberts (1963) for exposures in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E. (fig. 15), immediately north of the former coal-mining town of Cokedale, Mont. At the type section, the formation conformably and gradationally overlies the Eagle Sandstone and is 1,550 feet thick (fig. 16).

Weed (1893, p. 11) described the difference in lithology that is the basis for separating the Livingston Formation from the underlying Eagle Sandstone and stated that the two formations were separated by an unconformity. As a result of their regional studies in the Crazy Mountains basin, Stone and Calvert (1910, p. 761) recognized the Livingston Formation at the type locality as conformably overlying the Eagle. Roberts (1957, p. 47; 1963, p. B90) arbitrarily designated the top of an arkosic sandstone that overlies the uppermost minable coal bed of the Eagle Sandstone as the contact with the Livingston, and this horizon is taken as the base of the Cokedale. Some andesitic sandstone occurs in the upper part of the Eagle Sandstone, and some arkosic sandstone and coal occurs in the lower part of the Cokedale Formation; nevertheless, the indicated boundary is the most easily recognized contact in the Livingston area. A difference in physical and chemical properties of the coals in the upper part of the Eagle (bituminous-coking) compared with those in the lower part of the Cokedale (lignite-noncoking) is also a good reason to choose this boundary. A thin, black chert-pebble conglomerate that marks the top of the Eagle or base of the Claggett throughout much of south-central Montana (Hancock, 1918, p. 115; Knappen and Moulton, 1931, p. 37) was not found in the section at Cokedale.

LITHOLOGIC COMPOSITION

The Cokedale Formation consists of siltstone, sandstone, mudstone, water-laid tuff, bentonite, and carbonaceous claystone; and coal is present in the lower part (measured section 16). The sedimentary rocks were derived mostly from volcanic rocks of andesitic composition.

Siltstone forms about 50 percent of the Cokedale Formation. The siltstone is generally massive bedded, tuffaceous, and commonly olive gray, weathering to *in the type Livingston Group and Fort Union Formation, Cokedale, Mont.*

in millimeters. Analyses by R. F. Gantnier]

Heavy minerals [1]—Continued									Grain-size distribution for indicated diameter												
Rutile	Biotite	Leucoxene	Magnetite and ilmenite	Whitneyite	Hematite	Pyrite	Cassiterite	Soluble in acid	1.0	0.7	0.5	0.35	0.25	0.175	0.125	0.088	0.062	0.031	0.004	0.002	<0.002
0.4	0.7	0.7	13.8	0	2.1	0	0	20.2	0	0	0.1	0.9	13.2	19.2	16.5	9.1	6.2	12.0	17.1	1.8	3.9
0	.6	1.8	22.4	0	5.8	0	0	17.0	.1	.1	1.0	6.5	23.9	16.7	11.9	7.9	4.0	9.8	13.5	1.5	3.0
.2	0	.9	6.4	0	1.1	0	0	18.6	0	0	0	.1	6.8	24.2	21.9	8.8	6.3	8.9	15.4	2.1	5.5
.3	0	.5	6.6	.2	.3	0	0	18.2	0	.1	.5	1.5	6.2	17.8	15.3	7.9	10.8	6.2	23.6	3.5	6.6
0	0	1.0	19.7	0	2.3	0	0	15.6	1.6	2.6	9.2	11.2	16.0	9.3	7.2	4.8	4.9	8.6	16.3	2.0	6.3
.2	.4	.2	1.1	0	.6	0	0	15.7	5.6	4.1	4.6	8.2	16.1	8.6	8.5	7.4	7.1	15.4	10.0	1.9	2.5
0	0	.4	7.7	.2	1.3	0	0	15.8	0	Tr.	Tr.	1.5	7.3	15.5	9.6	7.0	6.4	10.1	29.7	4.0	8.9
0	.2	.7	7.5	0	.7	0	0	14.8	0	0	0	.3	9.0	17.9	15.3	11.0	7.4	7.7	23.6	1.7	6.1
0	.2	.8	2.8	0	.8	0	0	26.2	.2	.2	2.5	9.0	18.1	16.0	12.0	9.2	8.1	6.6	14.3	.8	3.0
0	0	1.0	15.5	.2	3.3	0	0	23.7	0	0	0	0	.7	10.8	24.6	17.8	12.7	8.4	17.5	2.5	5.0
0	0	.7	15.1	0	2.9	0	0	21.2	0	0	0	0	1.1	17.5	27.2	11.4	8.5	7.8	20.7	1.4	4.4
0	.2	.5	4.6	0	.7	0	0	29.9	0	0	0	Tr.	.5	20.5	26.3	15.1	10.7	5.2	16.7	1.7	3.3
0	0	.6	6.3	0	.2	0	0	30.4	.1	.1	.4	.3	.3	10.3	10.5	13.1	19.5	7.6	27.8	3.0	7.0
0	0	.7	9.3	.2	1.2	0	0	29.0	0	0	0	0	.1	.1	7.6	16.8	24.1	12.9	29.5	2.5	6.4
0	0	.4	2.2	0	.2	0	0	29.2	0	Tr.	.1	.3	1.0	6.7	16.7	13.1	11.4	6.7	34.7	3.0	6.3
0	0	.9	7.1	.3	1.9	0	0	32.7	.4	1.5	4.5	6.5	13.1	12.7	12.0	8.6	7.9	7.9	18.5	2.1	4.3
0	0	0	.5	0	0	0	0	16.7	0	0	0	0	2.7	15.9	16.7	11.0	8.3	7.6	29.6	2.9	5.3
0	.4	1.5	58.9	.7	1.3	0	0	12.6	0	0	0	.1	5.2	15.2	14.0	10.5	8.6	10.7	26.0	3.2	6.5
0	0	.2	1.7	.2	.2	0	0	15.2	0	0	0	.1	11.3	19.9	14.0	11.6	8.5	9.0	9.4	3.8	2.4
0	0	2.7	60.8	3.8	1.6	0	0	9.7	0	0	Tr.	.1	17.9	36.4	10.9	6.9	5.9	5.3	13.6	1.2	1.8
.2	0	.9	68.8	2.4	1.9	0	.4	(3)													
0	.5	0	62.0	5.6	.7	0	1.5	11.7	0	0	0	0	.1	1.7	17.2	16.1	11.9	7.6	34.1	3.2	8.1
.3	0	1.8	14.0	.7	1.8	.3	0	21.1	0	Tr.	3.6	10.1	13.4	12.3	10.6	8.9	9.3	6.1	19.4	2.5	3.8
.3	0	.5	13.3	1.1	1.6	.5	0	(3)													
.5	0	0	3.3	0	.2	0	0	(3)													
.5	0	1.9	3.8	4.5	.7	0	0	18.7	0	0	0	0	.1	3.5	21.4	22.0	13.3	9.9	21.4	3.3	5.1
0	0	0	.5	0	0	.5	0	18.3	0	0	0	0	.1	10.8	18.9	15.4	12.1	10.2	23.9	4.3	4.3
0	0	8.6	41.0	4.5	6.3	1.9	0	49.7	5.0	6.7	7.1	6.8	5.3	4.1	13.4	12.4	9.7	10.0	13.3	1.5	4.7
0	0	4.6	34.9	12.8	3.6	5.1	0	34.4	.3	1.3	3.7	13.2	10.1	9.5	7.8	7.5	7.4	12.9	22.0	3.1	1.2
0	0	3.9	3.9	4.4	.5	0	0	6.4	0	0	0	0	0	0	4.3	23.8	26.6	16.9	22.1	2.5	3.8

[3] Too firmly silica-cemented for mechanical analysis; sample crushed and separated for heavy-mineral analysis.

yellowish gray. In the lower part of the Cokedale, carbonaceous siltstone that contains abundant leaf impressions, pollen, and spores indicates a transition from brackish-water marine deposition of the Eagle Sandstone to continental deposition of the Cokedale. Locally, in the upper part of the formation, fresh-water mollusks are preserved.

Hard ridge-forming sandstone makes up about 35 percent of the formation. The sandstone beds are generally dusky yellow green, weathering to light olive; they are massive to thin bedded, crossbedded, fine to coarse grained, and locally conglomeratic. Many conglomeratic sandstones occur in scour-and-fill structures; mudstone fragments are common constituents of these deposits. Sandstone beds contain angular to subrounded grains of volcanic rock (predominantly microporphyritic and porphyritic andesite), plagioclase (andesine), heavy minerals, and quartz. The heavy minerals (in order of decreasing abundance) are diopsidic augite, magnetite, zircon, copper mineral, leucoxene, hematite, biotitemuscovite, epidote, pyrite, anatase, staurolite, hypersthene, sillimanite, garnet, sphene, corundum, tourmaline, and hornblende (table 6). Pebbles of volcanic rock include a distinctive welded tuff known to be indigenous only to the Elkhorn Mountains Volcanics west of this area (M. R. Klepper, oral commun., 1958). The oldest beds that contain these pebbles occur 600 feet above the base of the Cokedale Formation. Sandstone in the Cokedale contains much petrified wood and rare dinosaur bones. The sandstones are cemented mainly by silica, but the cement includes lesser amounts of calcite, zeolite minerals, and montmorillonitic clay. The dominant zeolite is heulandite, which commonly has a characteristic orange color.

Prominent beds of light-gray calcareous quartzose sandstone similiar to sandstone in the Eagle crop out 340 and 510 feet above the base of the Cokedale Formation (measured section 16); the uppermost sandstone is 16 feet thick and probably is the western tongue of the Parkman Sandstone of areas farther east (fig. 2). These sandstones are better sorted than other sandstones in the Cokedale and consist of 35 to 55 percent quartz grains and lesser amounts of plagioclase (andesine) and potassium feldspar (orthoclase). These sandstones also contain a heavy-mineral suite similar to that in the Eagle Sandstone at Cokedale. The heavy minerals (in

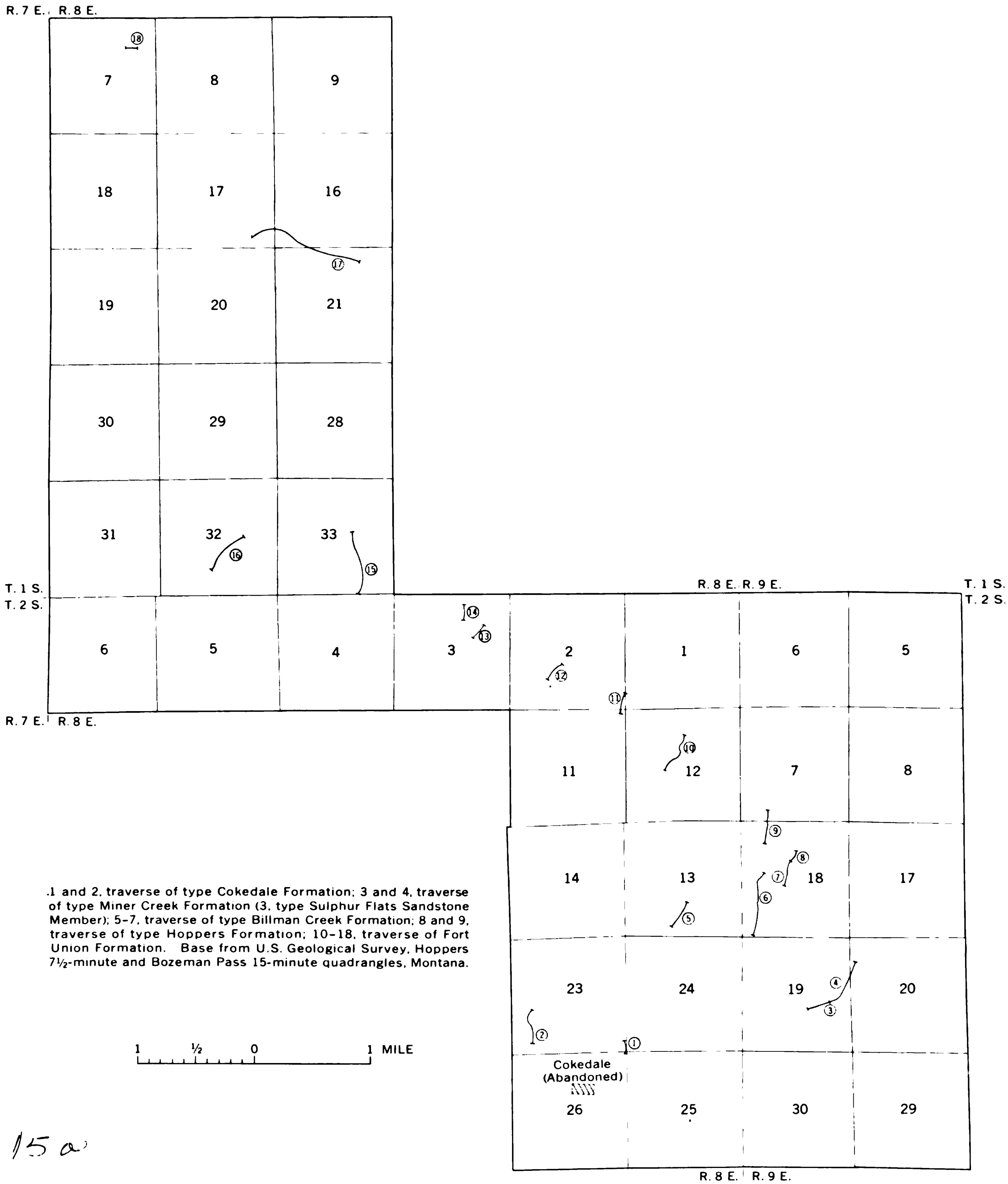


FIGURE 15.—Index map showing locations of measured units for the type Livingston Group and Fort Union Formation near Livingston, Mont.

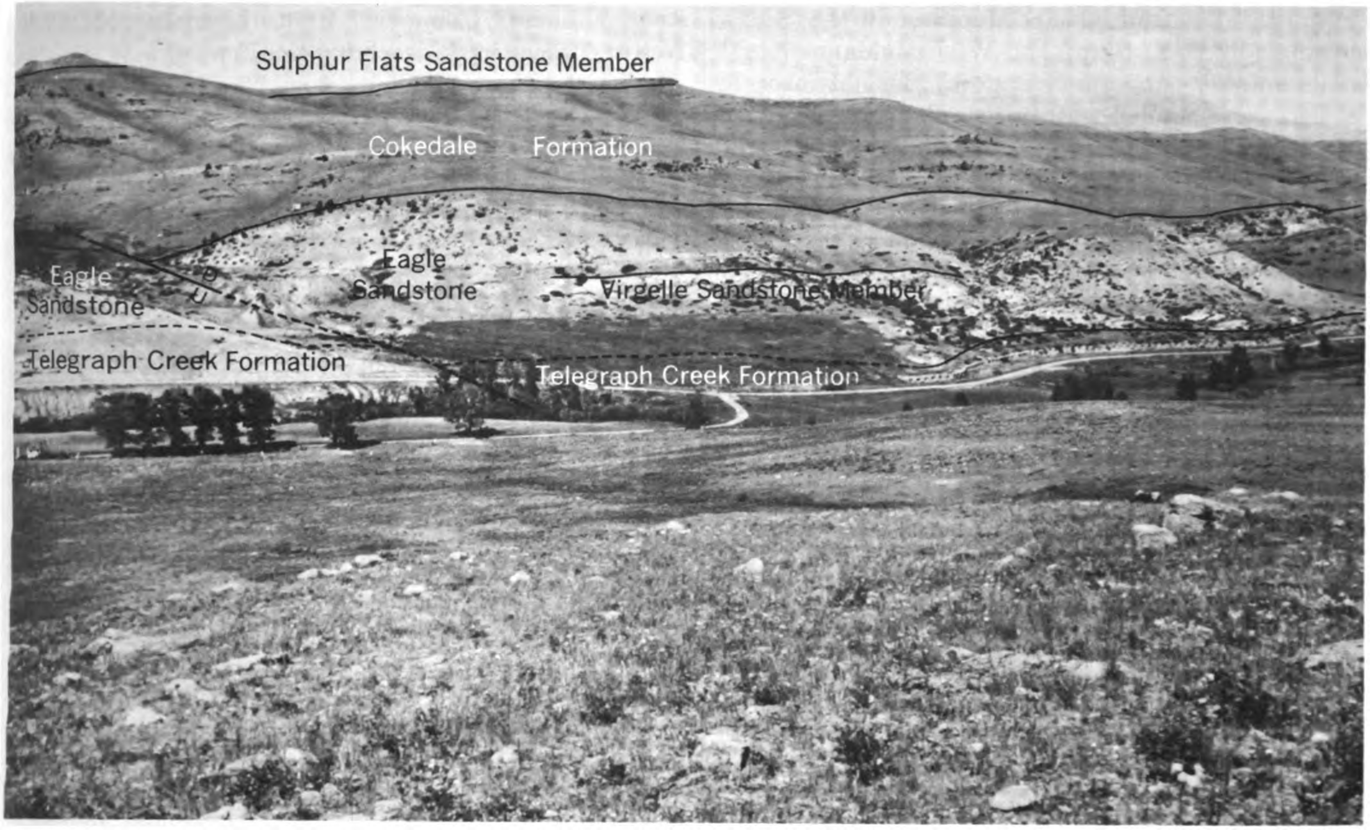


FIGURE 16.—Type Cokedale Formation near the former coal-mining town of Cokedale, Mont. At this locality the Cokedale conformably overlies the coal-bearing Eagle Sandstone and is overlain by the ridge-forming Sulphur Flats Sandstone Member of the Miner Creek Formation.

order of decreasing abundance) are zircon, biotite-muscovite, hypersthene, epidote, tourmaline, diopsidic augite, copper, magnetite, leucoxene, sphene, sillimanite, staurolite, anatase, topaz, garnet, corundum, and hematite (table 6).

AGE AND CORRELATION

Mudstone and sandstone from 660 to 680 feet above the base of the Cokedale Formation in the SW¼ sec. 23, T. 3 S., R. 8 E., contain an abundant pollen and spore flora (table 4). According to R. H. Tschudy (written commun., 1962), this flora is definitely older than the flora in the Mitten Black Shale Member of the Pierre Shale and most nearly resembles the flora from the Blair Formation of the Rock Springs region, Wyoming.

Samples (D1815-1 and D4120) collected near the middle of the Cokedale yielded a palynomorph assemblage common to the type Claggett Shale and the lower part of the type Judith River Formation (R. H. Tschudy, oral commun., 1968). This flora (table 4) suggests a deltaic environment of deposition to Tschudy.

Fragments of ?*Monoclonius* sp. that commonly occur in the Judith River Formation in Montana and in the "Pale Beds" at the top of the Belly River Formation in Alberta were identified by G. E. Lewis (written commun., 1963) from a sandstone 710 feet above the base of the Cokedale. The stratigraphic position of the Judith River Formation and its correlation with the Belly River Formation was first described by Hatcher and Stanton (1903).

In a siltstone bed (measured section 16, unit 167) 140 feet below the top of the Cokedale, the following fresh-water snails were collected by the writer and identified by D. W. Taylor (written commun., 1962):

Viviparus
cf. *Lioplacodes tenuicarinata* (Meek and Hayden)
Physa?

The Cokedale Formation is the westward nonmarine equivalent of the Claggett Shale and part of the Judith River Formation of central Montana, or part of the Two Medicine Formation of northwestern Montana (fig. 2). The Cokedale is the lower part of the leaf beds member of Weed's (1893, p. 22) Livingston Formation.

Tuffs in the middle part of the Cokedale Formation are persistent laterally and may correspond to Member D of the Livingston Group at Maudlow, Mont.

(Skipp and Peterson, 1965). Mapping in the Sedan quadrangle by B. A. Skipp and W. J. McMannis (oral commun., 1967) supports this correlation. Member D is a distinctive welded tuff unit similar to the welded tuffs of the middle member of the Elkhorn Mountains Volcanics. Robinson and Marvin (1967) compared the similar chemical composition and potassium-argon ages of the volcanic glass in these rocks. Radiometric studies by J. D. Obradovich (oral commun., 1968) indicate an age of 78 m.y. (million years) for the basal member of the Elkhorn Mountains Volcanics and 74±2 m.y. for the Butte Quartz Monzonite that cuts the middle member of the Elkhorn Mountains Volcanics; an age of 76±2 m.y. for the middle member of the Elkhorn Mountains Volcanics seems reasonable. This age is inferred for the middle part of the Cokedale Formation.

MINER CREEK FORMATION

The Miner Creek Formation was named by Roberts (1963, p. B90) for exposures along Miner Creek in the E½ sec. 19 and the NW¼ sec. 20, T. 2 S., R. 9 E. (fig. 15). The Miner Creek in the type section conformably overlies the Cokedale Formation and is 1,350 feet thick. The Miner Creek consists largely of alternating beds of siltstone and sandstone (fig. 17). The basal unit consists of a prominent ridge-forming sandstone and interbedded silicified tuff 160 feet thick. This unit is called the Sulphur Flats Sandstone Member, named for the section exposed along Miner Creek near Sulphur Flats in the SE¼ sec 19, T. 2 S., R. 9 E.

At Loweth, Mont., near the type Lennep Sandstone, J. R. Gill (oral commun., 1967) measured 785 feet of Miner Creek Formation overlying the Lennep Sandstone, and near Columbus, Mont., he measured 203+ feet of Miner Creek overlying the Lennep.

FIGURE 17.—Overturned sandstone and siltstone beds of the Miner Creek Formation exposed in roadcut at Bozeman Pass in the NE¼ sec. 13, T. 2 S., R. 7 E. View is east.

LITHOLOGIC COMPOSITION

The Miner Creek Formation consists of tuffaceous siltstone, volcanic lithic sandstone, volcanic sandstone, silicified tuff, and bentonite (measured section 17).

Massive-bedded tuffaceous siltstone forms 75 percent of the Miner Creek Formation. The siltstone in the upper part of the formation is olive gray and weathers to light olive gray. In the middle of the formation it is dusky yellow green and weathers to grayish yellow green, and in the lower part it is generally grayish olive green and weathers to grayish yellow green.

Sandstone forms about 20 percent of the formation. The sandstones are generally well bedded, fine to medium grained, subangular, and poorly to moderately sorted. Sandstone of the Sulphur Flats Sandstone Member, however, is massive, crossbedded, and poorly sorted. The sandstones are grayish green, weathering to light olive gray.

The sandstones of the Miner Creek Formation are composed primarily of volcanic rock fragments and plagioclase, which occurs as oscillation-zoned crystals and as crystal fragments. Very little quartz and potassium feldspar are present. The plagioclase feldspar ranges from andesine to labradorite and the potassium feldspar is orthoclase. Rock fragments are devitrified glass, fine-grained andesite, porphyritic and microporphyritic andesite, chert, and a few quartzose rocks. The feldspar and rock fragments are highly altered to carbonate and clay minerals.

Magnetite and diopsidic augite contents exceed 1 percent. Hematite is abundant as an iron oxide stain and as disseminated grains. Heavy minerals present (in order of decreasing abundance) are diopsidic augite, magnetite, zircon, hornblende, epidote, copper mineral, biotite-muscovite, hypersthene, hematite, leucoxene, corundum, topaz, cassiterite, garnet, sillimanite, tourmaline, sphene, rutile, staurolite, pyrite, and anatase (table 6). Other minerals identified are chlorite, nontronite, calcite, and apatite.

The grains are cemented by calcite, silica, and zeolite minerals (generally heulandite and lesser amounts of analcime and laumontite). Some heulandite cement has an orange tint due to included fine hematitic dust.

SULPHUR FLATS SANDSTONE MEMBER

The Sulphur Flats Sandstone Member consists mainly of tuff, quartzose sandstone, volcanic lithic sandstone, and conglomerate.

The tuffs are composed dominantly of plagioclase (laboradorite to andesine), volcanic rock fragments, and a clayey silt matrix. The distinguishable rock fragments are fine-grained andesites, porphyritic andesites, and devitrified glass. These fragments are generally very fine grained but contain plagioclase microlites, laths, and fragments dispersed in the matrix. An X-ray analysis of a water-laid tuff (measured section 17, unit 9) indicates that it contains approximately 17 percent quartz. Other samples may contain more silica. The tuffs are commonly silicified and form indurated chert-like beds that are pale pink or green.

Zeolite minerals are characteristic of the Miner Creek Formation and are present in the Sulphur Flats Sandstone Member in quantities exceeding 1 percent. The zeolites are present as void fillings between grains and as cavity fillings (1 to 13 percent). Some have an orange tint due to fine hematitic dust dispersed through the zeolite. Optical properties and X-ray analysis indicate that the zeolites are predominantly heulandite; analcime, laumontite, and clinoptilolite are present in trace amounts.

The dominant clinopyroxene is diopsidic augite. Concentration of this mineral and clinoptilolite gives the formation a distinctive green color. The heavy minerals present (in order of decreasing abundance) are diopsidic augite, zircon, magnetite, epidote, biotite-muscovite, copper mineral, tourmaline, corundum, hornblende, hypersthene, staurolite, hematite, leucoxene, rutile, sphene, pyrite, topaz, garnet, and sillimanite (table 6). Biotite in the Miner Creek Formation and particularly in the Sulphur Flats Member, is abundant and characteristically light bronze in color.

Magnetite content exceeds 1 percent in nearly all beds in the Sulphur Flats Member (table 6), and it is generally concentrated along bedding laminations. Magnetite content in the Sulphur Flats Member increases northward from the type section. In this direction the nonmarine Sulphur Flats Sandstone Member grades laterally to the marine Lennep Sandstone. Magnetite and other heavy minerals are concentrated along the ancient strand line between these stratigraphic units. Such a sedimentary magnetite deposit can be observed near Wilsall, Mont., in sec. 25, T. 4 N., R. 8 E. Stebinger (1914a, p. 329–337) studied similar deposits in the Horsethief Sandstone (stratigraphic equivalent of the Lennep) in northwestern Montana and attributed those strata to deposition along ancient beaches. Houston and Murphy (1962), in a regional study of similar deposits, concluded that the magnetite-bearing sandstones were concentrated as placer deposits along the margin of an ancient shore line complex formed during the eastward regression of the Late Cretaceous sea. Stratigraphically above the Sulphur Flats Member, sandstone beds of the Miner Creek Formation also contain concentrations of magnetite (table 6).

The basal and top sandstone beds of the Sulphur Flats Sandstone Member are distinctly different from other sandstone beds of the Livingston Group. The basal bed (measured section 17, unit 1) is a fine-grained calcareous mottled yellowish-gray quartzose sandstone, 6 to 20 feet thick. This excellent marker bed is persistent throughout the Livingston area. The sandstone is composed predominantly of quartz and contains lesser amounts of plagioclase (andesine), potassium feldspar, and bronze biotite; it is cemented by silica and zeolite minerals. A few volcanic rock fragments are also present. Sand grains are subangular to subrounded and moderately sorted. The basal sandstone is similar in mineralogy, grain size, color, mottling, sorting, and calcareous and zeolite cement to sandstone units of the Lennep Sandstone at Loweth, Mont. The mottling is due to differential weathering of less resistant calcareous material between clusters of zeolite minerals in the cement. At the top of the Sulphur Flats Member, indurated sandstone beds that form ridges are composed predominantly of subangular volcanic rock fragments and contain lesser amounts of plagioclase (andesine) crystals (measured section 17, unit 43). The fragments include a variety of volcanic debris; however, porphyritic and microporphyritic andesite and devitrified glass are most common. The sandstone is fine to coarse grained, poor to moderately sorted, and commonly crossbedded.

Age and Correlation

Stanton (in Stone and Calvert, 1910, p. 665) identified a Late Cretaceous marine fauna from sandstone assigned by Stone and Calvert to the Livingston Formation near Wilsall, Mont., in the NE¼ sec. 25, T. 4 N., R. 8 E. The sandstone at this locality occupies a sandy transitional zone between the Bearpaw Shale and the overlying Lennep Sandstone. J. R. Gill and the writer visited this locality (USGS Mesozoic loc. D3082) and obtained the following fossils identified by W. A. Cobban:

Calcareous worm tube:
- *Serpula* sp.

Pelecypods:
- *Pteria nebrascana* (Evans and Shumard)
- *Pteria* cf. *P. linguaeformis* (Evans and Shumard)
- *Ostrea* cf. *O. russelli* Landes
- *Crenella* n. sp.
- *Tancredia americana* (Meek and Hayden)
- *Callistra*? sp.
- *Mactra* cf. *M. alta* Meek and Hayden
- *Panope* sp.

Cephalopods:
- *Baculites* cf. *B. compressus* Say
- *Placenticeras meeki* Boehm

Only one baculite fragment was complete enough to suggest a species assignment. According to W. A. Cobban (written commun., 1961), this fragment most closely resembles an ornate variety of *Baculites compressus*, and the collection would be in the *Baculites compressus* zone or possibly the slightly younger *Baculites cuneatus* zone in the upper Campanian of Late Cretaceous age (fig. 2). The marine rocks from which these fossils were obtained can be traced from Wilsall northward into the type section of the Lennep Sandstone at the north end of the Crazy Mountains (J. R. Gill, oral commun., 1962). East of Livingston at Columbus, Mont., the Bearpaw Shale contains *Baculites reesidei* (W. A. Cobban, oral commun., 1968) indicating a younger age and marine environment for these rocks in that direction. South of Wilsall, in the Livingston area, these beds are represented by the nonmarine Sulphur Flats Sandstone Member of the Miner Creek Formation.

Near the close of Cokedale deposition the Bearpaw sea transgressed westward across the Crazy Mountains basin to the longitude of Wilsall, Mont. (fig. 2). Perhaps a decrease in the elevation and amount of erosion from the source area and (or) a slight uplift of the basin permitted marine deposition in the western part of the basin. When the Bearpaw sea subsequently withdrew eastward from the Crazy Mountains basin, the nonmarine Sulphur Flats Sandstone Member of the Miner Creek Formation and the marine Lennep Sandstone were deposited as regressive units.

In the area between Augusta and Wolf Creek, Mont., the St. Mary River Formation overlies the Horsethief Sandstone as shown in figure 2. The St. Mary River Formation is a thick sequence of continental rocks derived from a volcanic terrane, probably the Elkhorn Mountains Volcanics. The St. Mary River Formation closely resembles the upper part of the Livingston Group and can be similarly subdivided. The lower 1,200 feet of the St. Mary River Formation consists of greenish-gray sandstones and mudstones similar to the Miner Creek Formation. Overlying this lower member is 1,000 to 3,000 feet of grayish-red mudstone very similar to the Billman Creek Formation. Approximately 900 feet of volcanic sandstone similar to the Hoppers Formation overlies the grayish-red mudstone member.

A carbonaceous claystone 420 feet above the base of the Miner Creek Formation in sec. 19, T. 2 S., R. 9 E. (USGS Paleobotany loc. D1612) and a similar claystone 1,330 feet above the base of the Miner Creek in sec. 20, T. 2 S., R. 9 E. (USGS Paleobotany loc. D1613; table 4) contain a diagnostic pollen and spore flora (R. H. Tschudy, written commun., 1967). The genus of greatest stratigraphic significance in these samples is *Aquilapollenites*, of which the following species were found in the two samples: *Aquilapollenites attenuatus*, *A. polaris*, *A. calvus*, and *A. reticulatus*. *Aquilapollenites calvus* and *A. polaris* are species whose ranges include the Campanian and Maestrichtian. *Aquilapollenites attenuatus* and *A. reticulatus* have ranges limited to the upper one-fourth of the Campanian and the Maestrichtian. The pollen assemblage is closely similar to that of a zone rich in *Aquilapollenites* in the upper part of the Pierre Shale. The plant microfossils in samples from USGS Paleobotany localities D1612 and D1613 correlate with those in the upper part of the type Judith River Formation.

The Miner Creek Formation correlates eastward with the lower part of the Hell Creek Formation; and the basa lsandstone unit, the Sulphur Flats Sandstone Member, is the nonmarine facies of the marine Lennep Sandstone and the Horsethief Sandstone (fig. 2). The Miner Creek is the upper part of Weed's leaf beds (1893), p. 22).

BILLMAN CREEK FORMATION

The Billman Creek Formation was named by Roberts (1963, p. B91) for the nonmarine section exposed near Billman Creek in the S½ sec. 13, T. 2 S., R. 8 E., and the W½ sec. 18, T. 2 S., R. 9 E. (measured sections 5–7; fig. 15). The Billman Creek at the type section conformably overlies the Miner Creek Formation and is 2,590 feet thick. The Billman Creek is mostly mudstone but includes lesser amounts of sandstone, siltstone, claystone, and conglomerate (fig. 18). It is less resistant to weathering than adjacent formations and generally forms valleys. Throughout the western part of the Crazy Mountains basin, the formation is characteristically and conspicuously grayish red.

Weathering of volcanic deposits, which probably included a large volume of ash, west of Livingston during a period of reduced aggradation in the source area is suggested as the cause for this red-bed sequence.

Lithologic Composition

The Billman Creek Formation consists of alternately bedded mudstone, claystone, siltstone, and sandstone (measured section 18). Mudstone and claystone make up about 65 percent of the Billman Creek Formation and are commonly massive bedded and generally tuffaceous. Three representative samples of claystone average 40 percent montmorillonite, 50 percent mixed-layer montmorillonite-illite-vermiculite, 5 percent illite, and 5 percent chlorite (L. G. Schultz, oral commun., 1962). Mudstone and claystone in the upper part of the formation are olive black to olive gray and weather to light olive gray; in the middle part they are mostly grayish brown and weather to pale yellowish brown;

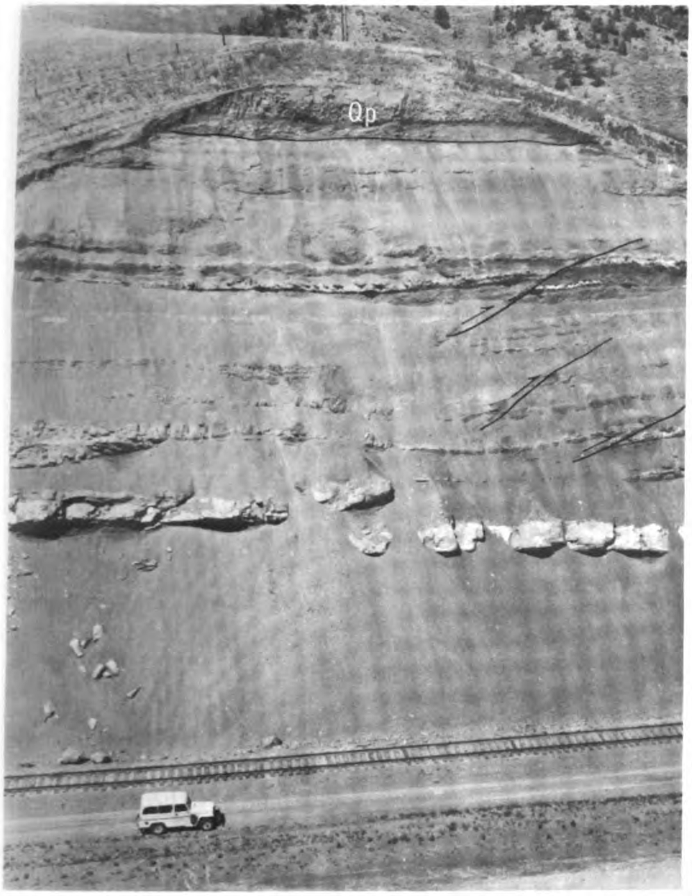


FIGURE 18.—Massive mudstones interbedded with sandstones and claystones typical of the Billman Creek Formation, exposed in large railroad cut in NE¼ sec. 15, T. 2 S., R. 8 E. The formation at this locality is overlain by a Quarternary pediment deposit (Qp). Note several small thrust faults; indicated direction of thrust is east.

and in the lower part they are mainly dusky red and weather to grayish red. Some beds in the lower part are grayish green, weathering to grayish yellow green. These multicolored very thick mudstones, particularly the grayish-red beds, characterize the Billman Creek Formation.

Sandstone and conglomerate channel fillings make up about 25 percent of the formation. These rocks are generally dusky yellow green and weather to grayish yellow green; they are composed of volcanic rock fragments, plagioclase (andesine), diopsidic augite, hornblende, magnetite, biotite, quartz, and orthoclase and are cemented by silica, calcite, clay, or zeolites. A 20-foot-thick persistent andesitic sandstone unit 95 feet above the base of the Billman Creek Formation contains abundant spherical calcareous sandstone concretions, generally 1 to 2 feet in diameter, and is an excellent marker bed (fig. 19).

FIGURE 19.—Massive to crossbedded andesitic sandstone 95 feet above the base of the Billman Creek Formation in the NE¼ sec. 19, T. 2 S., R. 9 E. Unit contains abundant spherical calcareous concretions which are persistent laterally.

The sandstones are composed predominantly of feldspar (3–17 percent) and rock fragments (20–80 percent). The feldspars include orthoclase and plagioclase (generally andesine) and are generally altered, some completely to clay. Quartz is present in amounts less than 10 percent. The rock fragmetns are fine-grained andesite and microporphyritic and porphyritic andesite. Many of these fragments are stained with hematite Many of these fragments are stained with hematite. The sand grains are very fine to medium, mainly subangular, and poorly to moderately sorted. The grains are cemented by calcite, silica, clay, and zeolite minerals, generally heulandite.

Diopsidic augite and magnetite are present in quantities exceeding 1 percent. The heavy minerals present (in order of decreasing abundance) are diopsidic augite, magnetite, zircon, hypersthene, hematite, sphene, leucoxene, biotite-muscovite, hornblende, garnet, epidote, copper mineral, corundum, and staurolite (table 6). Other minerals present are sericite, chlorite, and nontronite.

AGE AND CORRELATION

At the base of the upper third of the Billman Creek Formation a massive brownish-gray mudstone (measured section 18, unit 105) contains sporadic small calcareous concretions and fresh-water mollusks and gastropods. The mudstone yielded a distinct palynomorph assemblage (table 4) equivalent to microflora found in the type Colgate Member of the Fox Hills Sandstone at Glendive, Mont. (R. H. Tschudy, oral commun., 1968). A siltstone (measured section 18, unit 137) near the top of the Billman Creek contains macerated plant fragments and a poor palynomorph assemblage of Cretaceous age that suggests deposition in a brackish-water environment (R. H. Tschudy, oral commun., 1968).

Dinosaur bones of Maestrichtian (Lancian) age were described from several localities in the upper part of the Billman Creek Formation 13 miles east of Bozeman, Mont., by McMannis (1955, p. 1408).

The following fresh-water mollusks were collected from the middle part of the Billman Creek (measured section 18, unit 105) by the writer and identified by D. W. Taylor (written commun., 1962):

Fresh-water clams:
- *Sphaerium?*
- *Unionidae* indet.

Fresh-water snails:
- *Viviparus* sp.
- cf. *Lioplacodes tenuicarinata* (Meek and Hayden)
- *Physa* sp.

According to Taylor, these species are known from much of the Cretaceous and could not be precisely dated but were in accord with a Late Cretaceous age assigned on the basis of plant microfossils and fossil vertebrates.

The Billman Creek Formation is approximately the same age as the middle part of the Hell Creek Formation in central Montana (fig. 2). The Billman Creek is in the lower part of the conglomerate member of Weed's (1893, p. 30) Livingston Formation.

HOPPERS FORMATION

The Hoppers Formation is a nonmarine unit named by Roberts (1963, p. B91) for exposures near Hoppers Siding on the Northern Pacific Railway in the SW¼ sec. 7, and the NW¼ sec. 18, T. 2 S., R. 9 E. (fig. 15). The Hoppers Formation at the type section conformably overlies the Billman Creek Formation and is 965 feet thick. The Hoppers consists largely of massive sandstone beds that form valley walls above the easily eroded Billman Creek Formation.

Lithologic Composition

The Hoppers Formation is dominantly a volcanic lithic sandstone interbedded with mudstone and siltstone (measured section 19). Ridge-forming sandstone makes up 60 percent of the Hoppers Formation. The sandstone ranges from massive to thin bedded and is generally crossbedded. It is dusky yellow green and generally weathers olive gray; however, the basal 140 feet weathers a conspicuous yellowish gray and weathers to massive spheroidal shapes. The sandstones are mainly composed of quartz (7–12 percent); feldspar (10–22 percent, including orthoclase and plagioclase, generally andesine); and rock fragments (20–35 percent). The plagioclase composition is questionable due to intense alteration to clay. Rock fragments are fine-grained andesite, microporphyritic and porphyritic andesite, chert, and quartzite. The quartz has straight to strongly undulose extinction, and the grains have a few vacuoles and inclusions. The grains are cemented by calcite, silica, and zeolite minerals. The zeolite mineral is generally heulandite that has an orange tint due to inclusions of dispersed hematitic dust. The sandstone is fairly uniform in grain size (table 6) and moderately to well sorted. Grains are subangular to subrounded.

Much of the sandstone occurs as channel-fill deposits, which contain pebbles of mudstone and volcanic rock and fragments of wood and other plant debris. The basal sandstone beds of the Hoppers are massive, crossbedded, calcareous, generally conglomeratic, and cliff forming. Thin layers of ferromagnesian minerals, particularly magnetite, are common in these beds.

Clinopyroxene (dominantly diopsidic augite) and magnetite contents in two of the sandstone samples exceed 1 percent. Magnetite is concentrated in zones which accentuate bedding laminations. Heavy minerals present (in order of decreasing abundance), are diopsidic augite, magnetite, zircon, hematite, hypersthene, corundum, sphene, biotite-muscovite, epidote, leucoxene, hornblende, garnet, copper mineral, and staurolite (table 6). Other minerals present are nontronite, chlorite, and allanite.

About 25 percent of the formation is massive-bedded mudstone, which is olive gray and weathers to light olive gray. A few beds contain calcareous claystone concretions, and one was found that contains fresh-water mollusks.

Siltstone, which forms about 15 percent of the formation, is generally gradational with sandstone and is similar in color and mineral composition.

Age and Correlation

Fossils are rare in the Hoppers Formation, and the few that were found are not very helpful for precise dating. A massive siltstone (measured section 19, unit 42) in the upper part of the Hoppers yielded poorly preserved palynomorphs. According to R. H. Tschudy (oral commun., 1968) the presence of *Araucariacites*, code species V_2S–r6, *Classopollis*, and *Vitreisporites* suggests a Cretaceous age for this unit, and the presence of hystrichospheres and dinoflagellates suggests brackish-water depositional conditions.

In a dark-brown calcareous siltstone 395 feet from the top of the formation (measured section 19, unit 35), the following fauna was collected by the writer and identified by D. W. Taylor (written commun., 1962):

Fresh-water clam:
- *Rhabdotophorus aldrichi* (White)

Fresh-water snails:
Viviparus meeki Wenz
Lioplacodes indet.

According to Taylor, both *Rhabdotophorus aldrichi* and *Viviparus meeki* are known from the latest Cretaceous through the Eocene.

The Hoppers Formation correlates approximately with the upper part of the Hell Creek Formation of central Montana (fig. 2). The Hoppers is in the lower part of Weed's (1893, p. 30) conglomerate member.

CRETACEOUS AND TERTIARY SYSTEMS

UPPER CRETACEOUS AND PALEOCENE SERIES

FORT UNION FORMATION

The Fort Union Formation of Late Cretaceous and Paleocene age (Roberts, 1963, p. B89) overlies the type Livingston Group with apparent conformity. The Fort Union at Livingston, Mont., is a nonmarine sequence 6,615 feet thick (fig. 20) and consists of sandstone and conglomerate alternately bedded with siltstone and mudstone. It is subdivided into a lower conglomeratic sandstone member 980 feet thick, a middle member of sandstone and mudstone 3,835 feet thick, and an upper conglomeratic sandstone member 1,800 feet thick. The top is the present ground surface. These designations are somewhat general because the units vary considerably in average grain size and they are lenticular. The bedding and sedimentary structures of these rocks suggest flood-plain deposits on an extensive alluvial piedmont alternating with delta deposits in lakes. The source of the sediments was predominantly west of the Crazy Mountains basin; lesser amounts of sediment came from northwest and south of the basin.

The lithology of the rocks at the base of the Fort Union Formation differs markedly from the rocks of the underlying Livingston Group. Clasts in conglomerates of the Livingston are almost exclusively volcanic rock, whereas the conglomerates in the Fort Union contain igneous, metamorphic, and sedimentary clasts derived from Precambrian, Paleozoic, and Mesozoic formations. This significant change in provenance of the rocks, from a monolithologic to a heterolithologic unit, and an increase in fragment size suggest that the Fort Union Formation had a closer source area of additional relief and lithology subjected to greater erosion than did rocks of the Livingston Group. The lithology and size of clasts in the conglomeratic sequence at the base of the Fort Union indicate that the source area was probably a part of the Bridger uplift, which at this time was probably a broad feature that included most, if not all, of the Gallatin Valley. The abrupt change in lithology might indicate a short hiatus at the top of the Livingston; however, geologic mapping and similar spores and pollen immediately above and below

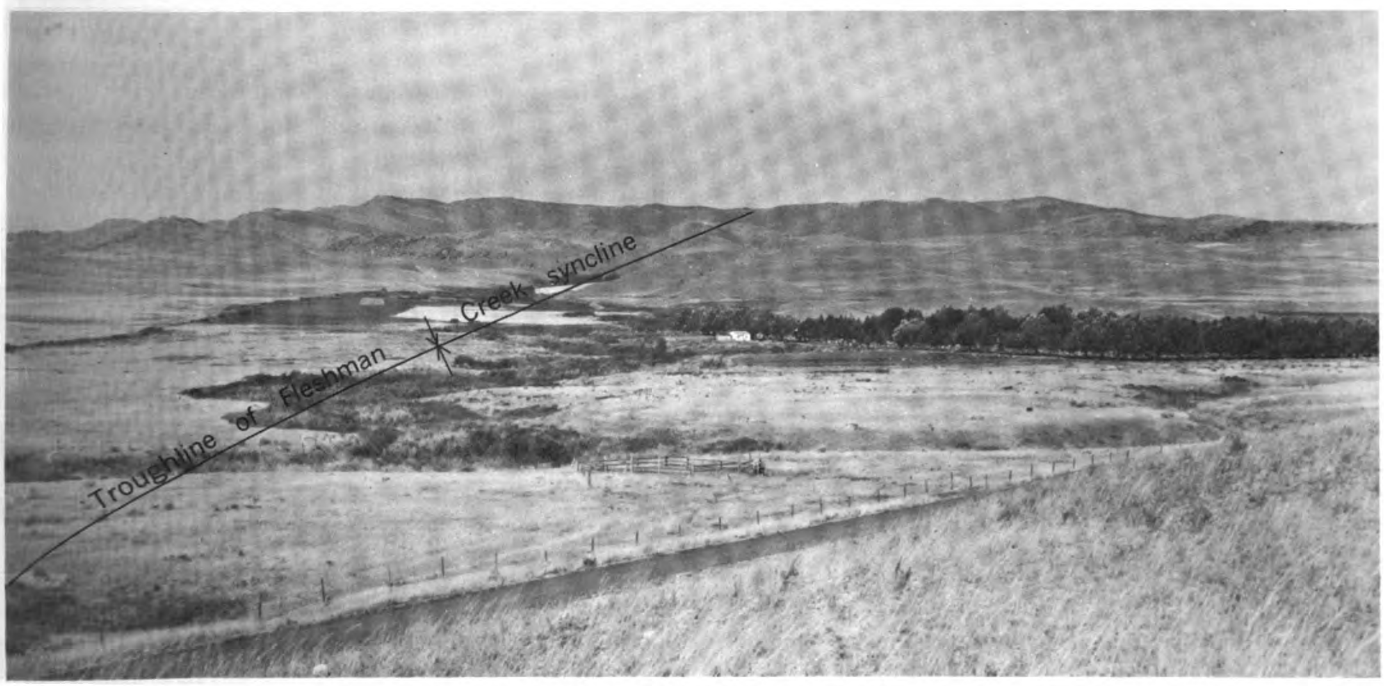


FIGURE 20.—Maximum thickness of the Fort Union Formation near the axis of the Fleshman Creek syncline. Reference section 20 was measured along the ridges at the left side of the photograph. View is northwest, parallel to the synclinal axis, from near Livingston, Mont.

the Fort Union-Livingston contact support a conformable designation.

Brown (1949) prepared a reconnaissance map of the contact between strata he assigned to the Cretaceous and those he assigned to the Paleocene around the edge of the Crazy Mountains basin.

LITHOLOGIC COMPOSITION

The thick sequence of continental sedimentary rocks of the Fort Union Formation includes coarse- to fine-grained clastic strata that vary rapidly in lithology and other characteristics (measured section 20). Massive conglomerates are common in the Fort Union in the westernmost part of the Crazy Mountains basin and are thickest, coarsest, and most abundant near the east flank of the Bridger Range (fig. 21). Cobbles and pebbles in the conglomerates are dominantly porphyritic and microlitic andesite but include lesser amounts of Precambrian igneous and metamorphic rock and Paleozoic and Mesozoic sedimentary rock. The conglomeratic units thin progressively eastward and southeastward by grading and interfingering laterally with sandstone, and the sandstones merge in turn with the finer grained clastic rocks in the central part of the basin.

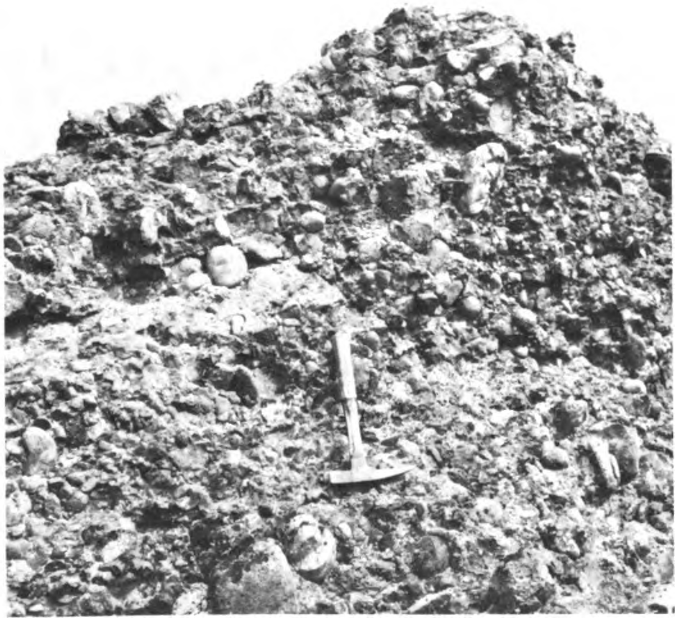


FIGURE 21.—Basal part of the upper conglomeratic sandstone member of the Fort Union Formation at Grassy Mountain in sec. 21, T 1 N., R. 7 E. Cobbles and pebbles are dominantly porphyritic and microlitic andesite with lesser amounts of Precambrian igneous and metamorphic rock and Paleozoic and Mesozoic sedimentary rock. Photograph by W. J. McMannis.

The sandstone units of the Fort Union Formation commonly are crossbedded or cross laminated and lenticular. Most of the crossbeds are foreset beds. In contrast, conglomerate units within the Fort Union are laterally extensive and apparently were deposited on a near-horizontal surface.

Most sandstone beds within the Fort Union Formation contain some interbedded conglomerate. Sandstones in scour-and-fill structures commonly contain scattered mudstone pebbles, which are tabular fragments of laminated mudstone that generally have rounded edges. Most mudstone pebbles were apparently derived from underlying beds or from the sides of the channels during periodic torrential floods. Exposed surfaces of these deposits have characteristic indentations or cavities because the mudstone fragments weather out more readily than the enclosing sandstone.

One striking characteristic of the Fort Union Formation near Livingston is a cyclic alternation of sandstone and mudstone (pl. 2; measured section 20) in graded beds. Thick- to thin-bedded sandstone units are commonly coarse grained in the lower part and grade upward to fine grained at the top. Bedding in these sandstone units changes gradually from thick bedded at the base to thin bedded in the upper part; also, these sandstone units become better sorted and more calcareous progressively upward.

Most of the calcareous sandstone beds weather dark yellowish brown or brownish gray, whereas the noncalcareous beds weather light olive gray or grayish yellow green. The calcareous or slightly calcareous beds and the coarser grained conglomerate beds form ridges, whereas the noncalcareous beds and the finer grained sandstone and mudstone form slopes. In general, sandstones in the Fort Union become gradually lighter colored toward the top of the formation.

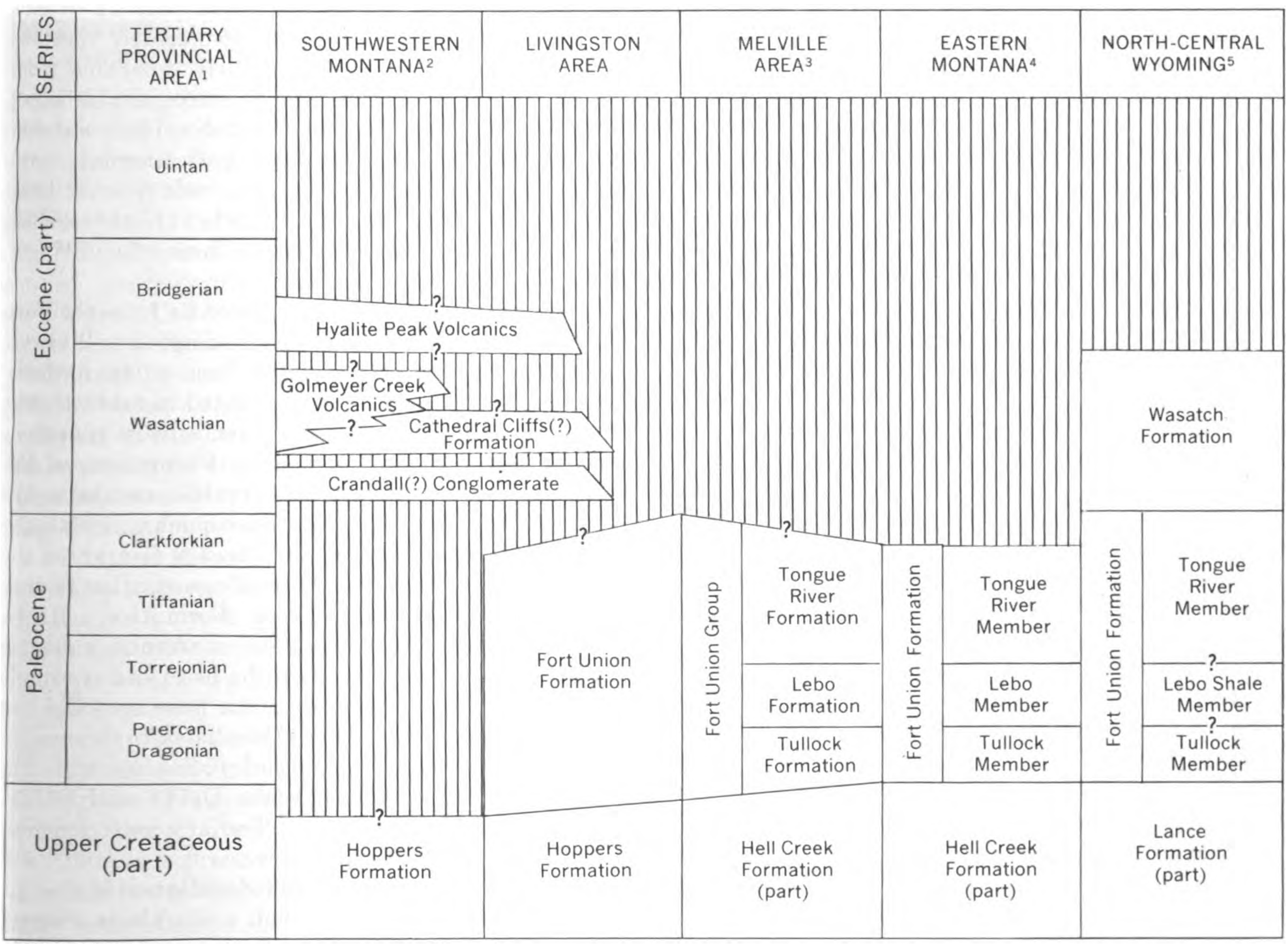
The sandstone units contain a large quantity of feldspar and lithic fragments of volcanic, metamorphic, and sedimentary rock; the grains are angular to subrounded. Samples examined for grain-size distribution indicate poor sorting (table 6). Feldspars include both orthoclase and plagioclase; the latter ranges in composition from andesine to labradorite. The cement consists of varying amounts of silica, calcite, or zeolite mineral.

The heavy minerals present (in order of decreasing abundance) are diopsidic augite, magnetite, zircon, hypersthene, garnet, hematite, epidote, sphene, leucoxene, biotite-muscovite, hornblende, corundum, rutile, staurolite, tourmaline, anatase, topaz, and copper mineral (table 6). Other minerals present are quartz, nontronite, chlorite, and zeolite. Quartz grains that have straight to strongly undulose extinction and a few vacuoles or inclusions suggest a possible metamorphic source for some of the sedimentary rock.

AGE AND CORRELATION

The lower part of the Fort Union Formation near Livingston, Mont., was assigned to the uppermost part of the Late Cretaceous by Roberts (1963, p. B89; 1965, p. B60). This assignment was based on paleontological data and tectonic implications of the rock types in the basal conglomeratic member of the Fort Union compared with conglomerates of the Livingston Group. Correlations and stratigraphic relations of the Fort Union at Livingston and adjacent areas are shown in figure 22.

Formations of the Livingston Group and members of the Fort Union Formation in the western part of the Crazy Mountains basin are so similar that it is difficult to distinguish one from the other. Weed (1893, p. 35) recognized the Fort Union Formation on the east side of the Crazy Mountains; however, on the west side of the Crazy Mountains near Livingston he included the Fort Union in his Livingston Formation. Weed (1893, p. 31) was well aware that his upper (conglomerate) unit might be separated from underlying rocks with additional field studies and that it probably correlated with the Fort Union. Later (Iddings and Weed, 1894), the Fort Union was included in the underlying Livingston Formation in the southern half of the Crazy Mountains basin. Stone and Calvert (1910, p. 555) were able to trace Upper Cretaceous formations westward along the Musselshell River in the northeastern part of the basin and show that these forma-



¹ Modified from Wood and others (1941).
² Modified from Pierce (1957; 1963); Chadwick (1969).
³ Modified from Simpson (1937); Stow (1946).
⁴ Modified from Brown (1962).
⁵ Modified from Mapel, Robinson, and Tehobald (1959).

FIGURE 22.—Correlation and stratigraphic relations of part of the lower Tertiary rocks of the Livingston area, Montana, with rocks of other areas in Montana and Wyoming.

tions grade into Weed's Livingston Formation. They demonstrated that Weed's Livingston Formation is a highly volcanic facies of the Claggett, Judith River, Bearpaw, Lennep, Lance (Hell Creek), and Fort Union Formations. Stone and Calvert (1910, p. 746) subdivided the Fort Union Formation near Harlowton, Mont., into two members and named the basal unit the Lebo Andesitic Member. Stone and Calvert (1910, p. 659) tentatively correlated the well-formed conglomerate on Brackett Creek on the east side of the Bridger Range (upper conglomeratic sandstone member) with light-colored sandstones near Clyde Park, Mont., that contained a Fort Union flora.

In the northeast part of the Crazy Mountains basin near Melville, Mont., Simpson (1937, p. 16–20), separated a Cretaceous-Tertiary transitional unit between what he defined as Hell Creek and Fort Union Formations and named the unit the Bear Formation. He assumed that beds up to and including the true dinosaur-bearing Lance and Hell Creek faunas belong in the Cretaceous and that overlying beds without dinosaurs (except by redeposition), but with Tertiary-type mammals, are Tertiary. His Bear Formation was given separate formational rank because it contained no diagnostic vertebrates and could not positively be included in either the Hell Creek or Fort Union; however, Simpson (1937, p. 21) favored inclusion with the Fort Union. The basal 80 feet of the Bear Formation (Simpson, 1937, p. 17) contained fragmentary dinosaur specimens which he interpreted as being redeposited from eroded underlying Hell Creek beds. The arbitrary top of the Bear Formation (Simpson, 1937, p. 17) was assigned to a 1-foot-thick bed that contains a freshwater invertebrate fauna. This fauna was presumed to be of Paleocene age. However, later studies of similar collections that contain this fauna in the western part of the basin indicate that the fauna is nondiagnostic. On the basis of a collection of plants from the Bear Formation that contained more Paleocene species than Cretaceous, Brown (1962, p. 7) assigned the formation to the Tertiary and placed the Cretaceous-Paleocene boundary at the contact of the Bear and Hell Creek Formations.

Simpson (1937, p. 21) divided the Lebo Andesitic Member of Stone and Calvert (1910) into two locally mappable units—the Lebo No. 1 (lower) and the Lebo No. 2 (upper). Simpson (1937, p. 25) proposed the name "Melville" for the formation overlying the Lebo No. 2 unit and suggested that future work might establish correlation with the Tongue River and perhaps Sentinel Butte Members of the Fort Union formation of eastern Montana. Stow (1946), as a part of his regional lithologic studies of Upper Cretaceous and Paleocene basin-fill sediments in the southeastern part of the Crazy Mountains basin, mapped the Tullock Formation from south-central Montana west to include Simpson's Bear Formation. He (1946, p. 678) also traced Simpson's Melville Formation southeast to Heart Mountain, Wyo., and considered the Melville to be equivalent to the Tongue River Formation. McMannis (1955, p. 1407) also recognized the Fort Union Formation along the western side of the basin including subdivisions corresponding to the ones recognized in the Livingston area.

Brown (1962, p. 17) collected fossil plants on Brackett Creek in sec. 9, T. 1 N., R. 7 E., southwest of Wilsall, Mont., which were the same species found in the Lebo and Simpson's Bear Formation on the east side of the Crazy Mountains. Although these collections were not strictly diagnostic, Brown assigned an early Paleocene age to about 1,500 feet of the upper part of Weed's Livingston Formation. He also commented that the strata at this locality are not clearly separable from the underlying Cretaceous beds by recognizable lithologic differences and well distributed unequivocal fossils. Dorf (in McMannis, 1955, p. 1409) assigned a probable Paleocene age to a flora from beds near Wilsall, Mont., which McMannis correlated with the middle sandstone and mudstone member near the Bridger Range.

Fine-grained clastic sedimentary rocks from the Fort Union (measured section 20) were sampled and examined for spores and pollen. On the basis of fauna from these samples (plant microfossils listed in table 4), the Cretaceous-Tertiary boundary is tentatively placed in the lower part of the Fort Union Formation, at the boundary between the lower and middle members. According to R. H. Tschudy (written commun., 1962), the lowest fossiliferous sample (D4105), 750 feet above the base, contains a Cretaceous assemblage similar to that obtained from the Hell Creek Formation. R. H. Tschudy (written commun., 1962) examined a sample (D1783) from 1,625 feet above the base and a sample (D1784) from 2,050 feet above the base and did not find Cretaceous fossils such as *Tricolpites interangulus*, *Schizosporus complexus*, or *Aquilapollenites* spp. The few species listed in table 4 (under D1783 and D1784) are characteristic of the early Tertiary or transgress the Cretaceous-Tertiary boundary.

The hystrichospheres and dinoflagellates in the uppermost Cretaceous palynomorph assemblage (sample D4105) indicate brackish-water deposition and the *Ghoshispora* probably grew in fresh-water lakes or ponds. As a whole, the palynomorph assemblage suggests that this sample was deposited in a deltaic environment.

On Willow Creek, in the NW¼ sec. 4, T. 1 S., R. 9 E., 9 miles north of Livingston, the writer collected a jaw and three teeth of a condylarth in Fort Union strata approximately 3,100 feet above the base (in Brown, 1962, p. 8, 17; Roberts, 1965, p. B60). This specimen was the first Paleocene mammal found west of the Crazy Mountains; it was identified by C.L. Gazin (written commun., 1958) as *Tetraclaeonodon* cf. *T. symbolicus* Gidley of middle Paleocene age, which has been described from the Lebo Member of the Fort Union. From beds at this locality, the writer also collected fresh-water mollusks identified by D. W. Taylor (written commun., 1962) as *Unionidae* indet., *Lioplacodes*? sp., and *Viviparus meeki* Wenz. These mollusks do not provide a precise age determination, but are in accord with the middle Paleocene age assignment of C. L. Gazin.

HEAVY-MINERAL SUITES IN THE FORT UNION FORMATION AND LIVINGSTON GROUP

Examination of heavy-mineral suites from Upper Cretaceous and lower Tertiary rocks has contributed to a better understanding of the regional stratigraphic relations. Stow (1938; 1946) first demonstrated a chronologic relationship between sedimentation and orogeny in the Crazy Mountains basin by heavy minerals. He identified characteristic mineral assemblages from known Upper Cretaceous and lower Tertiary formations in the northern part of the Bighorn Basin of Wyoming and, on the basis of relative frequency of significant minerals, extended correlations into the eastern part of the Crazy Mountains basin of Montana. In the western part of the Crazy Mountains basin, near Livingston, stratigraphic equivalents were similarly studied during the present investigation and the tabulation of data is shown in table 6. Stow (1938, p. 749) found that garnet, hornblende, kyanite, staurolite, tourmaline, and zircon were valuable for stratigraphic correlation or for ascertaining the source of the sedimentary rocks. In the Livingston area, anatase, diopsidic augite, garnet, rutile, tourmaline, and sillimanite have proved to be valuable minerals for these purposes. Diopsidic augite is limited to and common throughout the Livingston Group and Fort Union Formation and indicates a source from the Elkhorn Mountains Volcanics. Anatase is present in significant amounts only in the Cokedale Formation. Tourmaline and sillimanite are virtually restricted to the Cokedale and Miner Creek Formations. Zircon is present in all parts of the Livingston and Fort Union; however, its content is generally doubled in the Cokedale and Miner Creek Formations over its content in other parts of the sequence. The copper mineral, whitneyite, is present in significant amounts in the Cokedale and Miner Creek Formations, but also occurs in the underlying Eagle Sandstone. Garnet and rutile are common constituents in the Fort Union Formation, whereas they are uncommon in the Livingston Group. The nonopaque heavy minerals, except diopsidic augite, indicate a Precambrian source; however, Precambrian lithic fragments of pebble size or larger did not become common until the basal member of the Fort Union was deposited.

EOCENE SERIES

Volcanic and sedimentary units of Eocene age cap ridges in the northern part of the Gallatin Range. The sedimentary units consist chiefly of conglomerate and sandstone derived from lower Eocene volcanic rocks, Mesozoic and Paleozoic sedimentary rocks, and Precambrian metamorphic rocks. The volcanic units are dominantly flows and flow breccias. The source area for the sedimentary units was the uplifted parts of the Beartooth Range to the southeast and the Gallatin Range to the south. Volcanic vents in the Gallatin Range and perhaps vents in the Beartooth Range contributed andesitic rock to the sedimentary units. The volcanic extrusive units were from vents in the Gallatin Range to the south and the Emigrant Peak area in the Beartooth Range to the southeast. Thickness of the Eocene Series varies due to the amount of relief at the base of the sequence; the units thin northward; some units extend farther north than others; and the sequence is truncated northward by post-Eocene erosion.

CRANDALL(?) CONGLOMERATE

At the base of the Eocene sequence at Chimney Rock, 15 miles southwest of Livingston in T. 3 S., R. 8 E., are two conglomerate units. The lower conglomerate is probably the Crandall Conglomerate of Pierce (1957) in northwestern Wyoming, on the basis of its stratigraphic position, age assignment of the overlying unit, and lithologic similarities. The Crandall Conglomerate was tentatively assigned to the lower Wasatchian of early Eocene age by Pierce (1957, p. 613). Brown (1961, p. 1175) extended use of the name Crandall(?) Conglomerate west into north-central Yellowstone Park, and Rubel (1964, p. 42) described a similar conglomerate at Monument Peak north of Yellowstone Park.

The Crandall(?) Conglomerate at Chimney Rock is 160 feet thick and is a cliff-forming coarse conglomerate (fig. 23). The formation is composed dominantly of boulders and contains lesser amounts of cobbles and pebbles. Some boulders are as much as 5 feet in diameter; however, most are 1 to 2 feet in diameter. The

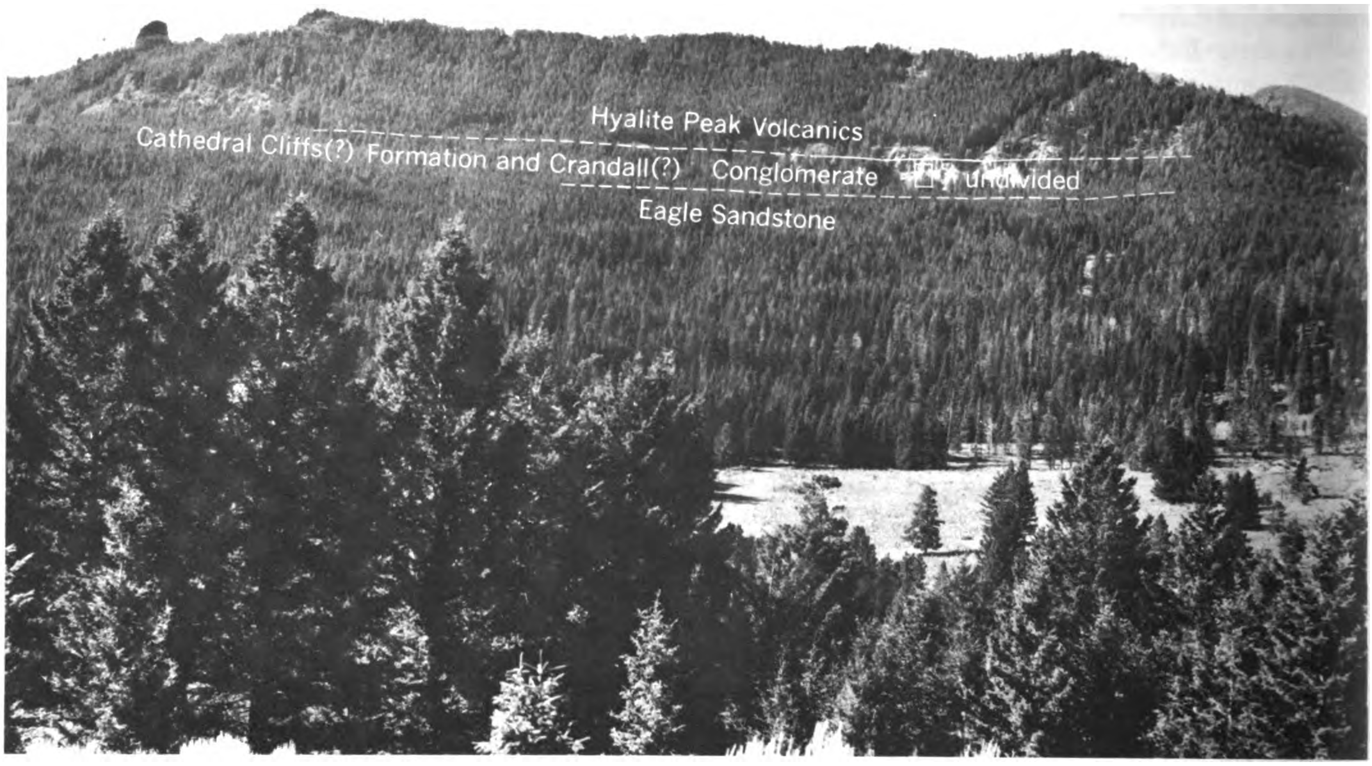


FIGURE 23.—Sedimentary and volcanic rocks of Wasatchian and Bridgerian ages overlying the Eagle Sandstone of Late Cretaceous age at Maxey Ridge at the northern end of the Gallatin Range. Outlined area enlarged in figure 24. Chimney Rock, prominent landmark in the area, is on the skyline on the upper left. View toward west.

clasts are subangular to well rounded but are commonly subrounded as shown in figure 24. Clasts are dominantly dacitic volcanic rock but include lesser amounts of Precambrian igneous and metamorphic rock and Paleozoic and Mesozoic sedimentary rock. The matrix is poorly sorted sand derived from similar rocks.

Stratification in the Crandall(?) Conglomerate is poor or absent. Sandstone lenses in the conglomerate are generally the only indication of bedding. Scour-and-fill structures are common.

Elsewhere in the Crazy Mountains basin, conglomerate of possible Eocene age occurs only in one very small area near the junction of the Crazy Mountains basin and Bighorn Basin. This conglomerate rests unconformably on tilted and eroded beds of the Fort Union Formation and is lithologically similar to the Crandall Conglomerate. Calvert (1917, p. 203) named this unit the Linley Conglomerate. There are no reported occurrences of rocks equivalent to the Crandall north of the Canyon Mountain anticline in the western part of the Crazy Mountains basin.

CATHEDRAL CLIFFS(?) FORMATION

The Crandall(?) Conglomerate is overlain by 60 to 80 feet of loosely consolidated slope-forming conglomerate. Its stratigraphic position and petrologic composition suggest that this upper conglomerate is a facies of the lower part of the "early acid breccia" of Hague (Hague and others, 1899) in the Absaroka Range, the Reese Formation of Calvert (1912b, p. 56) in the southern part of the Gallatin Range, or the Cathedral Cliffs Formation of Pierce (1963) in the Clarks Fork area of northwestern Wyoming. The unit consists of boulders (largest observed was 8 feet in diameter), cobbles, pebbles, and sand. The heterogeneous mixture indicates very rapid deposition. The Cathedral Cliffs(?) Formation is composed entirely of volcanic rock fragments, generally of andesitic composition, and may be a lateral sedimentary facies of the lower part of the Golmeyer Creek Volcanics (R. A. Chadwick, written commun., 1969) or the Golmeyer Creek's equivalents in the Beartooth and Absaroka Ranges (H. W. Smedes, oral commun., 1968). Locally

FIGURE 24.—Crandall(?) Conglomerate exposed on north side of Maxey Ridge in N½ sec. 31, T. 3 S., R. 8 E. Conglomerate composed dominantly of dacitic volcanic rock but contains lesser amounts of Precambrian igneous and metamorphic rocks and Paleozoic and Mesozoic sedimentary rocks. Note circled man for scale.

at the base of the Cathedral Cliffs(?) Formation in the Garnet Mountain area is a carbonaceous siltstone (McMannis and Chadwick, 1964, p. 18) that contains plant spores and pollen which were identified by R. H. Tschudy (written commun., 1962) as being of late early Eocene or Wasatchian provincial age of Wood and others (1941).

GOLMEYER CREEK VOLCANICS

A sequence of several thousand feet of andesitic flows, flow breccias, mudflows, and lahars in the central part of the Gallatin Range was named the Golmeyer Creek Volcanics by Chadwick (1969), and that name is herein adopted. This volcanic unit overlies the Cathedral Cliffs(?) Formation about 10 miles south of the Livingston area in the central part of the Fridley Peak quadrangle. This formation is not present at Maxey Ridge in the north end of the Gallatin Range. The Golmeyer Creek Volcanics, together with the underlying Cathedral Cliffs(?) Formation, form the "early acid breccia" of Hague (Hague and others, 1899) for the northern part of the Gallatin Range.

HYALITE PEAK VOLCANICS

The youngest volcanic unit in the northern part of the Gallatin Range is a sequence of andesitic flows and flow breccias named the Hyalite Peak Volcanics by Chadwick (1969), and that name is herein adopted. This volcanic unit unconformably overlies the Cathedral Cliffs(?) Formation in the northern part of the Gallatin Range (fig. 25). At Maxey Ridge this formation is approximately 1,500 feet thick and thickens southward. This andesitic unit is probably equivalent to the "early basic breccia" of Hague (Hague and

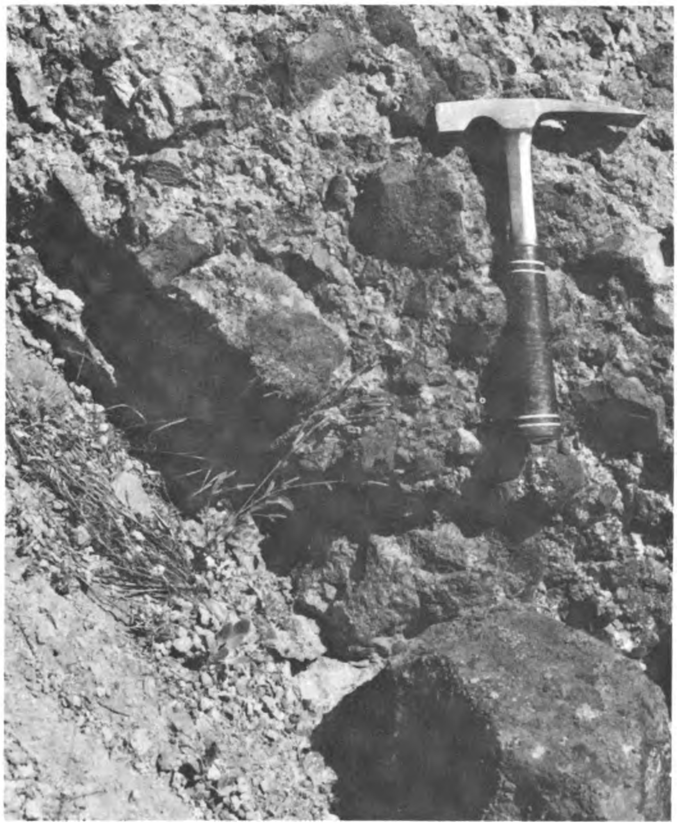


FIGURE 25.—Volcanic agglomerate or lahar in the Hyalite Peak Volcanics that overlie the Cathedral Cliffs(?) Formation at Maxey Ridge in the N½ sec. 31, T. 3 S., R. 8 E.

others, 1899), which has a Bridgerian age in the northern Absaroka Range and in the Yellowstone National Park area, Wyoming.

SELECTED STRATIGRAPHIC SECTIONS

Sedimentary sections measured, described, and sampled for stratigraphic and paleontologic control in southwestern Montana and north-central Wyoming as part of the investigation of the Livingston coal field are presented in the following pages. Twenty stratigraphic sections were selected as the most useful to provide a framework for stratigraphic and paleontologic studies of Cretaceous and Paleocene formations of southwestern Montana. More than one measured section is given for certain formations in which significant lateral variations in lithology are meaningful for a better understanding of its stratigraphy. These variations in lithology are best illustrated in selected sections that are normal to what was the strand line during deposition of that formation. Stratigraphic relations are summarized graphically in figures 2 and 22, and microfossil data are presented in tabulated form in tables 2 to 4. Four of the selected sections are type sections; one is redefined as a typical section; seven are designated as reference sections; and eight provide additional stratigraphic and paleontologic control.

The sections are arranged by formation in order of decreasing geologic age. Beds containing fossils are designated by their assigned fossil-collection number, for example, USGS Paleobotany locality D3512–T or USGS Mesozoic locality D581.

In the bed descriptions, rock names consist of a noun denoting the dominant constituent followed by adjectives denoting other constituents present. Terms describing grain size, hardness, thickness of bedding, color, and additional information—such as the presence of an unusual or distinctive mineral—are given.

METHODS OF STUDY AND DEFINITIONS OF TERMS

Stratigraphic sections were selected for completeness of the sequence and minimal structural complexity. The sections were measured by planetable and alidade and by tape and Brunton traverse. Representative samples were collected, generally from the middle of each lithologic unit. Descriptions of the stratigraphic units include megascopic and petrographic determinations of physical properties. Color designations were based on the "Rock-Color Chart" of the National Research Council (Goddard and others, 1948). The terminology applied to fragmental volcanic rocks is mainly that of Wentworth and Williams (1932, p. 45–53) and Williams, Turner, and Gilbert (1954, p. 149–150).

In referring to the bedding of the rocks, the following standard was used: **massive** means greater than 4 feet in thickness; **thick bedded** means 2 to 4 feet; **medium bedded,** 6 inches to 2 feet; **thin bedded,** 2 to 6 inches; and **very thin bedded,** ½ to 2 inches. **Platy** refers to beds ¹⁄₁₆ to ½ inch thick, and **laminae** are less than ¹⁄₁₆ inch.

Grain-size distributions for detrital rocks were determined by conventional sieve and pipette analyses. The following grain sizes are used: **granule** means more than 2 mm; **very coarse,** 1.00 to 2.00 mm; **coarse,** 0.50 to 1.00 mm; **medium,** 0.25 to 0.50 mm; **fine,** 0.125 to 0.25 mm; and **very fine** 0.0625 to 0.125 mm. Sorting refers to the distribution of individual grain-size classes. The following terms are used: **well sorted** means 90 percent of grains concentrated in one or two size classes; **medium sorted** or fairly well sorted, 90 percent of grains distributed in three or four size classes; and **poorly sorted,** 90 percent of grains scattered in five or more size classes. Claystone designates a rock composed essentially of clay-size particles. Mudstone designates nonfissile rocks that are predominantly of clay-size particles but contain lesser amounts of silt and very fine sand. Shale is regarded as a structural term for a fissile mudstone.

In describing the relative abundance of fossils, and occasionally of rock types or other material, the following standard was used: **very abundant** means that the fossils (or other constituents) compose most of the rock or unit; **abundant** means that they make up a considerable part; **plentiful,** that they can be found with ease; **common,** that they can be found in most hand specimens of rocks; **rare,** that they are generally difficult to find; and **very rare,** that considerable searching is necessary.

KOOTENAI FORMATION

Three stratigraphic sections of the Kootenai Formation are considered typical of the formation in the area west of Livingston. These are measured section 1 on the west flank of Chestnut Mountain anticline, measured section 2 on the south flank of the Canyon Mountain anticline, and measured section 3 on the north flank of the Canyon Mountain anticline. The lateral variation in lithology but uniform total thickness of the formation is well illustrated. Average grain size of the sandstone decreases from west to east. The well-exposed and accessible section on the west flank of the Chestnut Mountain anticline is here designated a reference section.

SECTION 1

Reference section of the Kootenai Formation, measured in the NE¼ sec. 25, T. 2 S., R. 6 E., Gallatin County, Mont.

[Measured by A. E. Roberts, 1956. See fig. 5]

	Ft	In.
Lower Cretaceous—Thermopolis Shale.		
Lower Cretaceous—Kootenai Formation:		
33. Claystone, olive-gray (5*Y* 4/1), calcareous; weathers to light olive gray (5*Y* 6/1)		7
32. Sandstone, thin-bedded, greenish-gray (5*GY* 6/1), very fine grained, silty, calcareous; weathers to dark yellowish orange (10*YR* 6/6)		7
31. Limestone, massive, dense, light-olive-gray (5*Y* 5/2), very fine grained, fossiliferous; probably of fresh-water origin; weathers to pale yellowish brown (10*YR* 6/2); contains abundant ostracodes	4	0
30. Siltstone, dusky-yellowish-brown (10*YR* 6/2), sandy, calcareous; contains stringers of carbonaceous material; weathers to moderate yellowish brown (10*YR* 4/2)		5
29. Siltstone, dusky-yellowish-brown (10*YR* 2/2), sandy, calcareous; weathers to moderate yellowish brown (10*YR* 5/4)		3
28. Claystone, dark-olive-gray (5*Y* 3/1), calcareous; weathers to pale yellowish brown (10*YR* 6/2)		3

SECTION 1—Continued

Reference section of the Kootenai Formation, measured in the NE¼ sec. 25, T. 2 S., R. 6 E., Gallatin County, Mont.—Con.

Lower Cretaceous—Kootenai Formation—Continued	Ft	In.
27. Limestone, irregularly bedded, thick-bedded, dense, silty, light-olive-gray (5*Y* 6/1), fine- to medium-grained, fossiliferous; probably of fresh-water origin; contains ostracodes and gastropods; weathers to yellowish gray (5*Y* 7/2)	2	4
26. Mudstone, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	1	0
25. Siltstone, grayish-green (10*GY* 5/2), noncalcareous; contains small (2–4 in. thick) irregularly shaped concretions near base; weathers to grayish yellow green (5*GY* 7/2)	4	6
24. Siltstone, dark-reddish-brown (10*R* 3/4), clayey; weathers to grayish red (10*R* 5/2)	14	7
23. Sandstone, massive, grayish-green (10*G* 5/2), medium-grained, poorly sorted, moderately indurated; grains composed of volcanic rock; weathers to greenish gray (5*GY* 6/1)	5	0
22. Sandstone, medium-bedded, greenish-gray (5*GY* 6/1), very fine grained, slightly indurated; weathers to light olive gray (5*Y* 6/1)	1	0
21. Siltstone, thin-bedded, grayish-red (10*R* 4/2), calcareous		7
20. Limestone, medium-bedded, grayish-red (10*R* 4/2), argillaceous; weathers to pale reddish brown (10*R* 5/4). Three inches of grayish-red (10*R* 4/2) calcareous siltstone 3 ft above the base of unit. This limestone unit is probably equivalent to the fossiliferous limestone that contains fresh-water gastropods and ostracodes and crops out on the north shore of Mystic Lake in sec. 25, T. 3 S., R. 6 E.	4	8
19. Siltstone, thin-bedded, grayish-red (10*R* 4/2), calcareous		4
18. Limestone, thin-bedded, grayish-red (10*R* 4/2), argillaceous		4
17. Siltstone, grayish-red (10*R* 4/2), slightly calcareous; weathers to pale reddish brown (10*R* 5/4)	1	0
16. Sandstone, crossbedded, mottled grayish-red (10*R* 4/2) and grayish-green (5*G* 5/2), very fine grained, silty, slightly calcareous, moderately indurated; weathers to pale reddish brown (10*R* 5/4) and grayish yellow green (5*GY* 7/2)	1	0
15. Siltstone, grayish-red (10*R* 4/2), slightly calcareous		6
14. Sandstone, crossbedded, mottled grayish-red (10*R* 4/2) and grayish-green (5*G* 5/2), very fine grained, silty; weathers to pale reddish brown (10*R* 5/4) and grayish yellow green (5*GY* 7/2)	3	6
13. Sandstone, very thin bedded and crossbedded, grayish-red (10*R* 4/2), very fine grained, slightly calcareous, indurated; weathers to pale reddish brown (10*R* 5/4)	18	5

SECTION 1—Continued

Reference section of the Kootenai Formation measured in the NE¼ sec. 25, T. 2 S., R. 6 E., Gallatin County, Mont.—Continued

Lower Cretaceous—Kootenai Formation—Continued	Ft	In.
12. Siltstone, thin-bedded to massive, multicolored (red, brown, purple, and green); contains some small channel-fill deposits of fine-grained sandstone and nodular concretions	7	1
11. Sandstone, thin-bedded to massive, mottled grayish-red (10*R* 4/2) and light brownish-gray (5*YR* 6/1), very fine grained, silty, poorly sorted, calcareous, indurated; weathers to mottled yellowish gray (5*Y* 8/1) and pale red (10*R* 6/2)	7	7
10. Siltstone, thin-bedded and crossbedded, multicolored (red and green), sandy; unit varies in thickness; lower 4 ft is a channel-fill deposit; contains small (6 in. in diameter or less) concretions and lenticular beds (1 ft thick or less) of calcareous sandstone	15	3
9. Limestone, medium- to thick-bedded, grayish-red (10*R* 4/2), argillaceous; some dendritic manganese staining; weathers to pale red (10*R* 6/2)	7	0
8. Siltstone, thin-bedded and crossbedded, multicolored (red, purple, and green), sandy, calcareous; contains lenticular calcareous sandstone beds (1 ft thick or less) and calcareous sandstone concretions	24	0
7. Claystone, multicolored (red, purple, yellow, and green), silty	9	10
6. Sandstone, thin-bedded to massive grayish-red (10*R* 4/2), very fine grained, silty, indurated, calcareous; mottled locally grayish red (10*R* 4/2) and greenish gray (5*GY* 6/1)	17	4
5. Mudstone, multicolored (purple and green), silty, soft	10	0
4. Siltstone, massive, grayish-red (10*R* 4/2), indurated, slightly calcareous; locally some greenish-gray (5*GY* 6/1) mottling; weathers to grayish orange pink (5*YR* 7/2)	26	6
3. Mudstone, massive, multicolored (purple, red, and green); upper 9 ft indurated, lower 5 ft thin to medium bedded containing lenticular beds of calcareous very fine grained sandstone; unit contains many calcareous very fine grained sandstone concretions as large as 2–3 ft in diameter	18	5
2. Sandstone, massive, medium-dark-gray (*N*4), very fine grained, silty, indurated; weathers to yellowish gray (5*Y* 7/2); lower contact gradational with underlying conglomerate	10	8
Pryor Conglomerate Member:		
1. Conglomerate, poorly bedded and crossbedded to massive; much of the unit is conglomeratic sandstone; pebbles are dominantly chert; sand grains of matrix composed dominantly of quartz and chert; lower half of unit contains several thin-bedded siltstones (1 ft or less in thickness)	37	0
Total thickness of Kootenai Formation	255	6

Upper Jurassic—Morrison Formation.

SECTION 2

Kootenai Formation measured in the NW¼ sec. 22, T. 3 S., R. 9 E., Park County, Mont.

[Measured by A. E. Roberts and C. A. Sandberg, 1959]

Lower Cretaceous—Thermopolis Shale.

Lower Cretaceous—Kootenai Formation:	Ft	In.
13. Siltstone and mudstone, massive, grayish-red (10*R* 4/2), calcareous in part; also some interbedded pale-yellowish-brown (10*YR* 6/2) claystone; approximately 20 ft above base is a nodular chert zone and about 5 ft below this zone the color changes to grayish red purple (5*RP* 4/2)	120	0
12. Tuff, thin- to thick-bedded, pale-yellowish-brown (10*YR* 6/2), silty; weathers to moderate yellowish brown (10*YR* 5/4); slight tendency to form ridges; considerable manganese staining on joint and fracture surfaces	7	0
11. Claystone, massive, grayish-red (5*R* 4/2), very calcareous; slight tendency to form ridges	8	0
10. Mudstone, massive, light-brownish-gray (5*YR* 6/1); contains streaks of grayish red (5*R* 6/2); poorly exposed; upper few feet is transitional with overlying unit	25	0
9. Claystone, massive, grayish-red (5*R* 4/2); poorly exposed; forms saddles in slopes	5	0
8. Limestone, irregularly bedded, light-olive-gray (5*Y* 6/1) and mottled yellowish-gray (5*Y* 8/1) and light-olive-gray; in part silty and sandy, containing rounded grains of quartz and chert; some thin discontinuous beds of silt and some small scour-and-fill channels that are less than 1 ft thick and contain small chert pebbles	7	0
7. Mudstone, massive, grayish-red (5*R* 4/2); poorly exposed	6	0
6. Siltstone, thin- to medium-bedded, pale-yellowish-brown (10*YR* 6/2), very calcareous; weathers to grayish orange (10*YR* 7/4); some manganese staining within the rock	5	0
5. Sandstone, thin- to thick-bedded, pale-yellowish-brown (10*YR* 7/2), fine- to medium-grained, very calcareous; weathers to pale yellowish brown (10*YR* 6/2); contains some hematite nodules; contains some ferromagnesian grains that are generally altered to limonite	8	0
4. Sandstone, massive and crossbedded, yellowish-gray (5*Y* 8/1), poorly sorted; quartz and chert grains cemented by calcite; weathers to grayish orange (10*YR* 7/4); scour-and-fill channel 4.5 ft above base· channel is 3.5 ft thick, 20 ft wide, and filled with quartz granules and chert pebbles; lower 3 ft contains many pebbles	20	0
3. Covered, probably light-yellowish-gray siltstone	8	0
2. Sandstone, medium- to thick-bedded, pinkish-gray (5*YR* 8/1), medium-grained; quartz grains cemented by calcite; unit slightly indurated but poorly exposed	4	0

SECTION 2—Continued

Kootenai Formation measured in the NW¼ sec. 22, T. 3 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Lower Cretaceous—Kootenai Formation—Continued		
Pryor Conglomerate Member:		
1. Conglomerate, massive and crossbedded, yellowish-gray (5*Y* 8/1); quartz and chert grains, granules, and pebbles cemented by calcite; much of unit is conglomeratic sandstone and contains many scour-and-fill channel deposits; ridge former	24	0
Total thickness of Kootenai Formation	247	0
Upper Jurassic—Morrison Formation.		

SECTION 3

Composite section of the Kootenai Formation, measured on the north side of Canyon Mountain in sec. 35, T. 2 S., R. 9 E., and adjusted with section of the Deerfield Oil Corp. Strong 1 well in sec. 11, T. 2 S., R. 9 E., Park County, Mont.

[Measured by A. E. Roberts and J. S. Hollingsworth, 1955.]

	Ft	In.
Lower Cretaceous—Thermopolis Shale.		
Lower Cretaceous—Kootenai Formation:		
18. Mudstone, thick-bedded, grayish-red (10*R* 4/2), soft	4	0
17. Siltstone, thin-bedded, light-gray; contains interbedded grayish-red shale	18	0
16. Mudstone, thin-bedded, micaceous, gray; contains interbedded medium-gray siltstone	9	0
15. Mudstone, thin-bedded to massive, silty, grayish-red to purple; contains thin interbedded shale, siltstone, and limestone	72	0
14. Limestone, medium-bedded, silty, mottled gray and grayish-red, finely crystalline	4	0
13. Siltstone, thin-bedded, micaceous, grayish-red; contains thin interbedded grayish-red shale	20	0
12. Mudstone, massive, silty, mottled light-gray and purple (5*RP* 4/2) and grayish-red	8	0
11. Limestone, medium-bedded, light-gray, finely crystalline	7	0
10. Mudstone, thin-bedded to massive, silty, micaceous, grayish-red and purple; contains thin interbedded siltstone and shale	45	0
9. Claystone, thin-bedded, light-gray to green (altered tuff bed?)	3	0
8. Mudstone, thin-bedded to massive, mottled gray and reddish-gray	22	0
7. Mudstone, thin- to thick-bedded, silty, pyritic, grayish-red; contains thin interbedded siltstone and purple shale	20	0
6. Claystone, thick-bedded, grayish-red, calcareous; weathers to pale yellowish brown (10*YR* 6/2)	3	0
5. Sandstone, medium-bedded, silty, pyritic, indurated yellowish-gray (5*Y* 7/2), fine- to very fine grained; angular grains	8	0
4. Mudstone, medium-bedded, sandy, calcareous, grayish-red; weathers to pale yellowish brown (10*YR* 6/2)	2	0

SECTION 3—Continued

Composite section of the Kootenai Formation, measured on the north side of Canyon Mountain in sec. 35, T. 2 S., R. 9 E., and adjusted with section of the Deerfield Oil Corp. Strong 1 well in sec. 11, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Lower Cretaceous—Kootenai Formation—Continued		
3. Sandstone, massive, crossbedded, pyritic, indurated, grayish-orange (10*YR* 7/4), very fine to fine-grained; ferromagnesian minerals altered to limonite give the orange color; weathers to moderate yellowish brown (10*YR* 5/4); angular to subrounded grains; ridge former	16	0
2. Sandstone, irregularly bedded, yellowish-gray (5*Y* 7/2) very fine to fine-grained, very poorly sorted, silty; weathers to dark yellowish orange (10*YR* 6/6); contains sporadic sand grains as large as granule size	7	0
Pryor Conglomerate Member:		
1. Conglomerate and sandstone, massive, crossbedded, calcitic, very poorly sorted; indurated Conglomerate composed mainly of subrounded chert pebbles. Sandstone composed dominantly of angular to subrounded quartz and quartzite grains. Unit has graded bedding—coarse at the base. Very prominent ridge former	24	0
Total thickness of Kootenai Formation	292	0
Upper Jurassic—Morrison Formation.		

THERMOPOLIS SHALE

Two stratigraphic sections of the Thermopolis Shale are considered to be typical of the formation in the area west of Livingston. These sections are approximately 15 miles apart and normal to what was the strand line during deposition of the Thermopolis. Clastic sedimentary rocks in the measured sections change systematically in grain-size distribution and sorting from west to east. Section 4 was measured on the north side of Rocky Creek Canyon, and section 5 was measured on the north side of Canyon Mountain. The section in Rocky Creek Canyon is here designated a reference section because of its completeness, accessibility, and contained microflora (table 2). Section 6, the Skull Creek Shale section of Mapel (1959, p. 39), was sampled for paleobotanical control for measured sections 4 and 5 and is included here as a reference section.

SECTION 4

Reference section of the Thermopolis Shale, measured on the north side of Rocky Creek Canyon in the SW¼ sec. 20, T. 2 S., R. 7 E., Gallatin County, Mont.

[Measured by A. E. Roberts, 1964.]

	Ft	In.
Lower Cretaceous—Mowry Shale.		
Lower Cretaceous—Thermopolis Shale:		
Upper sandstone member:		
28. Sandstone, fine-grained, uncemented; partly altered to a moderate-yellowish-brown (10*YR* 5/4) clay	1	0

443-754 O - 72 - 5

SECTION 4—Continued

Reference section of the Thermopolis Shale, measured on the north side of Rocky Creek Canyon in the SW¼ sec. 20, T. 2 S., R. 7 E., Gallatin County, Mont.—Continued

Lower Cretaceous—Thermopolis Shale—Continued

Upper sandstone member—Continued

	Ft	In.
27. Sandstone, medium- to thick-bedded, very fine to fine-grained, well-sorted, calcareous, indurated, medium-gray (*N*5); weathers to yellowish gray (5*Y* 7/2). Contains heavy-mineral suite that excellently marks individual layers. These layers are commonly crossbedded in beds as much as 6 in. thick. Some large plant fragments were found on bedding surfaces, and a few bedding surfaces are ripple marked. A few of the sandstone beds contain claystone pebbles. In weathered outcrop, heavy minerals alter to limonite and hematite	29	10
26. Mudstone, massive, carbonaceous, olive-black (5*Y* 2/1); weathers to light gray (*N*7); USGS Paleobotany loc. D3512–U, 7 ft above base of unit	30	0
25. Sandstone, medium- to thick-bedded, very fine to fine-grained, indurated, medium-light-gray (*N*6); weathers to yellowish gray (5*Y* 7/2). Bedding surfaces are covered with carbonaceous trash. Some bedding surfaces are rippled marked, and many have marine worm(?) trails and groove and small flute casts. Contains heavy-mineral suite. Between the sandstone beds are thin layers of carbonaceous claystone or siltstone. USGS Paleobotany loc. D3512–T, 9.5 ft above base of unit	31	6
Total thickness of upper sandstone member	92	4

Middle shale member:

	Ft	In.
24. Mudstone and interbedded siltstone and sandstone. The volume of sandstone in this unit gradually increases upward; the unit is a transition zone between the underlying shale unit and the overlying sandstone unit. The upper 5 ft is dominantly sandstone. The mudstone is massive, olive black (5*Y* 2/1), and weathers to medium light gray (*N*6). The sandstone is thin bedded, very fine grained, silty, medium gray (*N*5), and weathers to light olive gray (5*Y* 5/2). Most beds contain plant fragments. Bedding surfaces are commonly ripple marked	37	6

23. Shale, massive, carbonaceous, tuffaceous, olive-black (5*Y* 2/1); weathers to medium light gray (*N*6). Lower 10 ft contains poorly sorted sand grains. Bentonite beds were noted as follows:

Feet above base of unit	*Thickness in inches*
5	5
9	1
15	4
34.5	2
50.3	1
53.2	7
58.1	1

	Ft	In.
USGS Paleobotany loc. D3512–M is 5 ft above base of unit; USGS Paleobotany loc. D3512–N, 31 ft above base of unit; USGS Paleobotany loc. D3512–O, 48 ft above base of unit; and USGS Paleobotany loc. D3512–P, 63 ft above base of unit	101	0
22. Sandstone, thin-bedded, very fine to medium-grained, poorly sorted, carbonaceous (?), tuffaceous, medium-dark-gray (*N*4); weathers to very light gray (*N*8) and has some limonitic alteration. Very small selenite crystals in areas of limonitic alteration. Also contains approximately 10 percent interbedded brownish-black (5*YR* 2/1) shale	10	7
21. Sandstone and interbedded shale (sandstone approximately 75 percent). Sandstone is thin bedded, very fine grained, silty, light gray (*N*7), and weathers to light olive gray (5*Y* 5/2). Basal 1 ft is bentonitic. Shale is brownish black (5*YR* 2/1) and weathers to medium light gray (*N*6)	13	6
20. Shale, tuffaceous, brownish-black (5*YR* 2/1); weathers to medium light gray (*N*6); contains very small selenite crystals throughout; unit is partly altered	2	8
19. Sandstone, thin-bedded, very fine grained, silty, light-gray (*N*7); weathers to light olive gray (5*Y* 5/2); much limonitic weathering; some very small selenite crystals in small rosettes on bedding surfaces	1	0
18. Shale, dark-gray (*N*3); weathers to medium light gray (*N*6); contains very few (less than 5 percent) thin beds or lenses of very fine grained sandstone. USGS Paleobotany loc. D3512–F, 1 ft above base of unit; USGS Paleobotany loc. D3512–G, 15 ft above base of unit; USGS Paleobotany loc. D3512–H, 30 ft above base of unit; USGS Paleobotany loc. D3512–I, 45 ft above base of unit; USGS Paleobotany loc. D3512–J, 60 ft above base of unit; USGS Paleobotany loc. D3512–K, 75 ft above base of unit; and USGS Paleobotany loc. D3512–L, 90 ft above base of unit	96	0

SECTION 4—Continued

Reference section of the Thermopolis Shale, measured on the north side of Rocky Creek Canyon in the SW¼ sec. 20, T. 2 S., R. 7 E., Gallatin County, Mont.—Continued

	Ft	In.
Lower Cretaceous—Thermopolis Shale—Continued		
Middle shale member—Continued		
17. Sandstone and interbedded shale (sandstone approximately 70 percent). Sandstone is thin bedded, very fine to fine grained, silty, indurated, calcareous, medium gray (*N*5), and weathers to light gray (*N*7). Shale is carbonaceous, dark gray (*N*3), and weathers to medium light gray (*N*6)	22	10
16. Shale and interbedded sandstone (shale approximately 60 percent). Shale is carbonaceous, dark gray (*N*3), and weathers to medium light gray (*N*6). Sandstone is thin bedded, very fine to fine grained and silty. Although lithologically similar to unit 15, this unit is less indurated	7	10
15. Sandstone and interbedded shale (sandstone is approximately 80 percent). Sandstone is thin bedded, very fine to fine grained, silty, indurated, calcareous, medium gray (*N*5), and weathers to light gray (*N*7). Most bedding surfaces are covered with worm (?) trails and groove and small flute casts. Contains plant fragments. Shale in very thin interbeds is carbonaceous, dark gray (*N*3), and weathers to medium light gray	19	7
14. Shale and interbedded sandstone (shale is approximately 80 percent). Shale is dark gray (*N*3) and weathers to medium light gray (*N*6). It is very carbonaceous, containing abundant plant fragments. Sandstone is thin bedded, very fine grained, calcareous, very light gray (*N*8), and weathers to yellowish gray (5*Y* 8/1) and moderate yellowish brown (10*YR* 5/4). Some bedding surfaces are covered with worm(?) trails and groove and small flute casts. USGS Paleobotany loc. D3512–D, 5 ft above base of unit	10	2
13. Shale, dark-gray (*N*3); weathers to medium light gray (*N*6). Contains many calcareous lenses and a few nodules and septarian concretions that weather to grayish orange (10*YR* 7/4) to yellowish gray (5*Y* 7/2). This unit is less indurated than the overlying unit. The weathered surface of the outcrop has an overall yellowish-gray (5*Y* 7/2) appearance due to the presence of the many weathered calcareous chips, whereas the overlying unit is a uniform medium light gray (*N*6). USGS Paleobotany loc. D3512–A, 1 ft above base of unit; USGS Paleobotany loc. D3512–B, 15 ft above base of unit; and USGS Paleobotany. loc. D3512–C, 28 ft above base of unit	29	4
Total thickness of middle shale member	352	0
Lower sandstone member:		
12. Sandstone, thin- to medium-bedded, very fine grained, silty, light-brownish-gray (5*YR* 6/1); weathers to light gray (*N*7)	4	5
11. Claystone, massive, olive-gray (5*Y* 4/1); weathers to yellowish gray (5*Y* 8/1); contains some carbonaceous material	3	8
10. Sandstone, thin-bedded, very fine grained, silty, light-brownish-gray (5*Y R*6/1); weathers to light gray (*N*7) and has some limonitic staining; bedding surfaces are covered with marine worm(?) trails and groove casts and other sole marks of undetermined origin	8	5
9. Sandstone, thin- to medium-bedded, fine-grained, well-sorted, well-indurated (almost a quartzite), very pale orange (10*YR* 8/2); weathers to grayish orange (10*YR* 7/4); composed dominantly of clean quartz grains and contains a few laminae of heavy minerals	6	6
8. Sandstone, very thin bedded, very fine grained, silty, micaceous, quartzose, medium-gray (*N*5); weathers to yellowish gray (5*Y* 7/2)	4	8
7. Sandstone, thin- to medium-bedded, fine-grained, well-indurated (almost a quartzite), mottled light-brownish-gray (5*YR* 6/1) and brownish-gray (5*YR* 4/1); irregular base due to filling of mud cracks at the top of the underlying unit	1	1
6. Claystone, thick-bedded, carbonaceous, brownish-gray (5*YR* 4/1); weathers to light olive gray (5*Y* 6/1)	3	2
5. Sandstone, massive, fine-grained, well-sorted, well-indurated (almost a quartzite), very pale orange (10*YR* 8/2); weathers to grayish orange (10*YR* 7/4); composed dominantly of clean quartz grains and contains few heavy minerals	7	1
4. Sandstone, thin- to medium-bedded, very fine grained, micaceous, quartzose, medium-light-gray (*N*6); weathers to light olive gray (5*Y* 6/1) and bears considerable dark-hematitic staining; contains few scattered carbonaceous fragments	2	2
3. Sandstone, very thin bedded, very fine grained, silty, micaceous, quartzose, medium-gray (*N*5); weathers to yellowish gray (5*Y* 7/2)	2	5

SECTION 4—Continued

Reference section of the Thermopolis Shale, measured on the north side of Rocky Creek Canyon in the SW¼ sec. 20, T. 2 S., R. 7 E., Gallatin County, Mont.—Continued

	Ft	In.
Lower Cretaceous—Thermopolis Shale—Continued		
Lower sandstone member—Continued		
2. Sandstone, thin- to medium-bedded, fine-grained, well-sorted, well-indurated (almost a quartzite), very pale orange (10*YR* 8/2); weathers to grayish orange (10*YR* 7/4); composed dominantly of clean quartz grains and contains few laminae of heavy minerals	2	10
1. Sandstone, thin-bedded, fine-grained, well-sorted, quartzose, indurated (but less than overlying unit), mottled light-gray (*N*7) and medium-light-gray (*N*6); weathers to mottled yellowish gray (5*Y* 7/2) and very light gray (*N*8); the lower 6 in. is hematitic	2	3
Total thickness of lower sandstone member	48	8
Total thickness of Thermopolis Shale	493	0
Lower Cretaceous—Kootenai Formation.		

SECTION 5

Composite section of the Thermopolis Shale, measured on the north side of Canyon Mountain in sec. 35, T. 2 S., R. 9 E., and adjusted with section of the Deerfield Oil Corp. Strong 1 well in sec. 11, T. 2 S., R. 9 E., Park County, Mont.

[Measured by A. E. Roberts, 1961]

	Ft	In.
Lower Cretaceous—Mowry Shale.		
Lower Cretaceous—Thermopolis Shale:		
Upper sandstone member:		
19. Sandstone, thin-bedded, silty, micaceous, glauconitic, feldspathic, slightly calcareous, very fine to fine-grained, light-gray; contains reddish-orange specks of hematite; angular grains	24	0
18. Mudstone, thin-bedded to massive, silty, micaceous, pyritic, dark-gray; contains thin interbedded siltstone	42	0
17. Sandstone, thin- to thick-bedded, well-indurated micaceous, pyritic, very fine to fine-grained, greenish-gray (5*G* 6/1); weathers to dark yellowish brown (10*YR* 4/2); contains a heavy-mineral suite and a few sporadic claystone pebbles	39	0
Total thickness of upper sandstone member	105	0
Middle shale member:		
16. Siltstone, thin-bedded, sandy, micaceous, slightly calcareous, light-medium-gray (transitional unit between underlying shale and overlying sandstone)	10	0
15. Mudstone, thin-bedded to massive, silty, micaceous, pyritic, dark-brownish-gray; slightly carbonaceous near top of unit	39	0

SECTION 5—Continued

Composite section of the Thermopolis Shale, measured on the north side of Canyon Mountain in sec. 35, T. 2 S., R. 9 E., and adjusted with section of the Deerfield Oil Corp. Strong 1 well in sec. 11, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Lower Cretaceous—Thermopolis Shale—Continued		
Middle shale member—Continued		
14. Sandstone, thin-bedded, calcareous, micaceous, very fine grained, gray	6	0
13. Shale, silty, calcareous, dark-gray	5	0
12. Siltstone, thin-bedded, calcareous, light-brownish-gray	4	0
11. Shale, silty, dark-brownish-gray	9	0
10. Shale, silty, slightly calcareous, pyritic, glauconitic in lower part, carbonaceous in upper part; dark-gray; contains abundant spores and pollen	125	0
9. Siltstone, thin-bedded, calcareous, pyritic, dark-gray	5	0
8. Shale, pyritic, dark-gray to black; contains spores and pollen	95	0
7. Siltstone, thin-bedded, calcareous, pyritic, medium-gray; contains thin interbedded dark-gray shale	33	0
6. Siltstone, thin- to thick-bedded, slightly calcareous, medium-gray	35	0
5. Shale, dark-gray to black	24	0
Total thickness of middle shale member	390	0
Lower sandstone member:		
4. Sandstone, thick-bedded, fine-grained, quartzose, yellowish-gray (5*Y* 8/1); weathers to grayish orange (10*YR* 7/4)	3	0
3. Siltstone, thin-bedded, yellowish-gray	6	0
2. Sandstone, thick-bedded, fine- to medium-grained quartzose, yellowish-gray (5*Y* 7/2); weathers to dark yellowish orange (10*YR* 6/6); subrounded, well-sorted grains; ridge former	23	0
1. Sandstone, thin-bedded, very fine grained, very light gray (*N*8); weathers to grayish yellow (5*Y* 8/4); contains some very thin beds of medium-gray (*N*5) siltstone	3	0
Total thickness of lower sandstone member	35	0
Total thickness of Thermopolis Shale	530	0
Lower Cretaceous—Kootenai Formation.		

SECTION 6

Reference section of the Skull Creek Shale, measured in the SW1/4 sec. 25, T. 49 N., R. 83 W., near Buffalo, Wyo.

[Modified from Mapel (1959, p. 39)]

	Ft	In.
Lower Cretaceous—Newcastle Sandstone.		
Lower Cretaceous—Skull Creek Shale:		
6. Shale, grayish-black, laminated; some interlaminated light-gray siltstone in basal 10–15 ft; USGS Paleobotany loc. D3842–C, 55 ft above base of unit	85	0

SECTION 6—Continued

Reference section of the Skull Creek shale, measured in the SW¼ sec. 25, T. 49 N., R. 83 W., near Buffalo, Wyo.—Continued

Lower Cretaceous—Skull Creek Shale—Continued	Ft	In.
5. Siltstone, tan to light-gray, calcareous, thin-bedded, contains a few plant fragments; forms ledge	2	6
4. Shale and siltstone, interbedded and interlaminated; becomes more silty toward top; grayish-black shale; brown siltstone	19	0
3. Siltstone, brown, calcareous, thin-bedded; contains a few large steel-gray calcareous siltstone concretions; forms ledge	2	0
2. Shale and siltstone, interbedded and interlaminated; grayish-black shale; brown siltstone. USGS Paleobotany loc. D3842-B, 39 ft above base of unit; USGS Paleobotany loc. D3842-A, 23 ft above base of unit	47	0
1. Shale, gray to black, bentonitic; a zone of ferruginous siltstone concretions near middle of unit; poorly exposed	19	0
Total thickness of Skull Creek Shale	174	6

Lower Cretaceous—Cloverly Formation.

MOWRY SHALE

Two stratigraphic sections of the Mowry Shale are considered to be representative of the formation in the area west of Livingston. Section 7 was measured on the north side of Rocky Creek Canyon, and section 8 was measured on the north side of Canyon Mountain. The sequence at Rocky Creek Canyon is dominantly tuffaceous and carbonaceous, which suggests relative quiet brackish-water deposition. The sequence at Canyon Mountain is dominantly massive-bedded mudstone and silty shale, which suggests shallow restricted marine deposition. The section in Rocky Creek Canyon is here designated a reference section because of its microflora (table 2) and accessibility. Section 9, the Mowry Shale section of Mapel (1959, p. 42), was sampled for paleobotanical control for measured sections 7 and 8; it is included here as the typical section of the Mowry Shale.

SECTION 7

Reference section of the Mowry Shale, measured on the north side of Rocky Creek Canyon in the SW¼ sec. 20, T. 2 S., R. 7 E., Gallatin County, Mont.

[Measured by A. E. Roberts, 1964]

Upper Cretaceous—Frontier Formation.

Lower Cretaceous—Mowry Shale:	Ft	In.
28. Shale and mudstone, tuffaceous, brownish-gray (5*YR* 4/1) and grayish-olive-green (5*GY* 3/2); weathers to yellowish gray (5*Y* 7/2); contains some (approximately 25 percent) interbedded siltstone and porcelanitic sandstone; very poorly exposed	185	0
27. Bentonite, badly weathered and poorly exposed	2	0

SECTION 7—Continued

Reference section of the Mowry Shale, measured on the north side of Rocky Creek Canyon in the SW¼ sec. 20, T. 2 S., R. 7 E., Gallatin County, Mont.—Continued

Lower Cretaceous—Mowry Shale—Continued	Ft	In.
26. Sandstone, thin- to medium-bedded, very fine to fine-grained, indurated, calcareous, light-olive-gray (5*Y* 6/1); weathers to yellowish gray (5*Y* 8/1). Unit contains approximately 20 percent interbedded claystone	38	8
25. Shale, tuffaceous, brownish-gray (5*YR* 4/1); weathers to yellowish gray (5*Y* 7/2) and light gray (*N*7). Between 7 and 13 ft above base, unit contains some thin interbedded very fine grained sandstone	34	8
24. Sandstone, thin- to thick-bedded, fine- to coarse-grained, poorly sorted, indurated, calcareous, light-olive-gray (5*Y* 6/1); weathers to yellowish gray (5*Y* 8/1). Between 9 and 11 ft above base, unit is very fine grained to silty and is thin bedded	14	10
23. Shale, tuffaceous, brownish-gray (5*YR* 4/1); weathers to yellowish gray (5*Y* 7/2) and light gray (*N*7)	18	0
22. Siltstone, thin-bedded, calcareous, indurated, carbonaceous, medium-gray (*N*5); weathers to grayish yellow green (5*GY* 7/2)	1	0
21. Shale, tuffaceous, brownish-gray (5*YR* 4/1); weathers to yellowish gray (5*Y* 7/2) and light gray (*N*7)	23	0
20. Sandstone, thin- to thick-bedded, fine- to coarse-grained, poorly sorted, indurated, calcareous, light-olive-gray (5*Y* 6/1); weathers to yellowish gray (5*Y* 8/1); contains zones of abundant clay pebbles and cobbles and some large plant fragments	24	0
19. Shale, tuffaceous, brownish-gray (5*YR* 4/1); weathers to pinkish gray (5*YR* 8/1). At 30 ft above base, a 1-ft-thick layer of very carbonaceous claystone contains thin streaks of coal	76	0
18. Claystone, very tuffaceous (probably a weathered bentonite), olive-gray (5*Y* 4/1); weathers to light gray (*N*8)	2	8
17. Claystone, light-olive-gray (5*Y* 6/1) at base; gradually darkens upward to olive black (5*Y* 2/1). Upper part contains reddish-orange specks of heulandite	4	7
16. Sandstone, thin-bedded, very fine grained, silty, friable, light-gray (*N*7); weathers to light olive gray (5*Y* 5/2)	11	0
15. Siltstone, thin-bedded, indurated, calcareous, carbonaceous, medium-gray (*N*5); weathers to grayish yellow green (5*GY* 7/2)	1	0
14. Sandstone, thin-bedded, very fine grained, silty, tuffaceous, friable, light-gray (*N*7); weathers to light olive gray (5*Y* 5/2)	9	7
13. Claystone, tuffaceous, olive-gray (5*Y* 4/1); weathers to yellowish gray (5*Y* 8/1)	1	0
12. Bentonite		3
11. Claystone, carbonaceous, brownish-black (5 *YR* 2/1); weathers to light brownish gray (5*YR* 6/1)	1	5

SECTION 7—Continued

Reference section of the Mowry Shale, measured on the north side of Rocky Creek Canyon in the SW¼ sec. 20, T. 2 S., R. 7 E., Gallatin County, Mont.—Continued

Lower Cretaceous—Mowry Shale—Continued	*Ft*	*In.*
10. Sandstone, thin-bedded, very fine grained, silty, tuffaceous, friable, light-gray (*N*7); weathers to light olive gray (5*Y* 5/2); contains plant fragments. Approximately 90 percent of unit is composed of uncemented sand grains	16	0
9. Claystone, tuffaceous, grayish-olive-green (5*GY* 3/2); weathers to pale olive (10*Y* 6/2)	1	4
8. Sandstone, thin-bedded, very fine grained, silty, light-gray (*N*7); weathers to light olive gray (5*Y* 5/2)	1	8
7. Claystone, tuffaceous, grayish-olive-green (5*GY* 3/2); weathers to pale olive (10*Y* 6/2)	4	2
6. Sandstone, thin-bedded, very fine grained, silty, light-gray (*N*7); weathers to light olive gray (5*Y* 5/2)	2	0
5. Claystone, tuffaceous, olive-gray (5*Y* 4/1); weathers to yellowish gray (5*Y* 8/1). USGS Paleobotany loc. D3513–B	5	10
4. Sandstone, thin-bedded, very fine grained, silty, light-gray (*N*7); weathers to light olive gray (5*Y* 5/2)	1	0
3. Claystone, tuffaceous, grayish-olive-green (5*GY* 3/2); weathers to pale olive (10*Y* 6/2)	11	4
2. Sandstone, thin-bedded, very fine grained, silty, light-gray (*N*7); weathers to light olive gray (5*Y* 5/2)	2	0
1. Claystone, tuffaceous, light-olive-gray (5*Y* 6/1) at base; gradually darkens upward to olive black (5*Y* 2/1). Upper 6 in. is very carbonaceous—almost a dirty coal. USGS Paleobotany loc. D3513–A	3	0
Total thickness of Mowry Shale	497	0

Lower Cretaceous—Thermopolis Shale.

SECTION 8

Composite section of the Mowry Shale, measured on the north side of Canyon Mountain in sec. 34, T. 2 S., R. 9 E., and adjusted with section of the Deerfield Oil Corp. Strong 1 well in sec. 11, T. 2 S., R. 9 E., Park County, Mont.

[Measured by A. E. Roberts, 1961]

Upper Cretaceous—Frontier Formation.

Lower Cretaceous—Mowry Shale:	*Ft*	*In.*
17. Siltstone, thin-bedded, dark-grayish-brown	4	0
16. Shale, silty, dark-grayish-brown	26	0
15. Shale, silty, dark-gray	24	0
14. Mudstone, massive, silty, mottled grayish-green and grayish-brown; contains reddish-brown specks and floating sand grains	16	0
13. Shale, silty, micaceous, pyritic, dark-brownish-gray; contains very thin beds of coal and siltstone	58	0
12. Sandstone, medium-bedded, micaceous, glauconitic, very fine grained, greenish-gray	5	0

SECTION 8—Continued

Composite section of the Mowry Shale, measured on the north side of Canyon Mountain in sec. 34, T. 2 S., R. 9 E., and adjusted with section of the Deerfield Oil Corp. Strong 1 well in sec. 11, T. 2 S., R. 9 E., Park County, Mont.—Continued

Lower Cretaceous—Mowry Shale—Continued	*Ft*	*In.*
11. Claystone, greenish-gray	5	0
10. Siltstone, thin-bedded, micaceous, pyritic, gray	12	0
9. Shale, silty, micaceous, dark-grayish-brown	4	0
8. Sandstone, medium-bedded, slightly calcareous, micaceous, pyritic, very fine to fine-grained, light-greenish-gray; subrounded grains	11	0
7. Siltstone, thin-bedded, gray; contains interbedded gray shale; siltstone contains reddish-brown specks	18	0
6. Shale, silty, micaceous, pyritic, dark-gray; contains thin interbedded siltstone	30	0
5. Mudstone, thin-bedded to massive, silty, micaceous, pyritic, dark-brownish-gray mottled with red and green; contains thin interbedded siltstone	67	0
4. Sandstone, thin-bedded, micaceous, glauconitic, indurated, greenish-gray; angular grains	4	0
3. Mudstone, thin-bedded to massive, silty, micaceous, pyritic, dark-brownish-gray; contains thin interbedded siltstone	22	0
2. Shale, glauconitic, greenish-gray	4	0
1. Mudstone, thin-bedded to massive, silty, micaceous, pyritic, dark-brownish-gray; contains thin interbedded siltstone and very fine grained sandstone	110	0
Total thickness of Mowry Shale	420	0

Lower Cretaceous—Thermopolis Shale.

SECTION 9

Typical section of the Mowry Shale, measured about one-half of a mile north of the North Fork of Sayles Creek in secs. 5 and 6, T. 51 N., R. 83 W., near Buffalo, Wyo.

[Modified from Mapel (1959, p. 42)]

Upper Cretaceous—Frontier Formation.

Lower Cretaceous—Mowry Shale:

Siliceous shale member:	*Ft*	*In*
23. Shale, dark-gray to black; weathers to dark gray. Brittle 6-in.-thick bed of hard silty sandstone near middle of unit; USGS Paleobotany loc. D3843–F, 10 ft above base of unit	27	0
22. Sandstone, silty to very fine grained, thin-bedded; forms ledge	14	0
21. Bentonite, pale-yellow	2	0
20. Shale, gray, siliceous, brittle; weathers to light gray; contains abundant fish scales. USGS Paleobotany loc. D3843–E, 2 ft above base of unit	10	0
19. Siltstone, light-gray, hard; forms ledge	2	0
18. Shale, dark-gray; weathers to light gray; contains a few beds of light-gray siltstone	58	0
17. Bentonite, pale-green to light-gray	2	0

SECTION 9—Continued

Typical section of the Mowry Shale, measured about one-half of a mile north of the North Fork of Sayles Creek in secs. 5 and 6, T. 51 N., R. 83 W., near Buffalo, Wyo.—Continued

	Ft	In.
Lower Cretaceous—Mowry Shale—Continued		
Siliceous shale member—Continued		
16. Shale, gray, siliceous, brittle; weathers to light gray; contains abundant fish scales and several thin beds of bentonite less than 1 ft thick. USGS Paleobotany loc. D3843-D, 30 ft above base of unit	110	0
15. Bentonite, light-gray	2	0
14. Shale, gray, brittle, locally slightly silty; weathers to light gray	25	0
13. Bentonite, light-gray	2	6
12. Shale, gray, brittle; weathers to light gray; contains several thin beds of bentonite less than 1.5 ft thick	46	0
11. Bentonite, light-gray	2	6
10. Shale, gray, brittle; weathers to light gray; contains fish scales; thin beds of bentonite about 1 ft thick near middle of unit	22	0
Total thickness of siliceous shale member	325	0
Black shale member:		
9. Mostly concealed; appears to be mainly soft black shale that contains ironstone concretions which weather to purplish black; USGS Paleobotany loc. D3843-C, 11 ft above base of unit	41	0
8. Bentonite, light-yellowish-gray	4	0
7. Shale, grayish-black, soft, poorly exposed	50	0
6. Bentonite, light-gray	2	0
5. Shale, grayish-black, poorly exposed; contains a few ironstone concretions	29	0
4. Bentonite, light-gray	2	0
3. Shale, grayish-black, soft, bentonitic. USGS Paleobotany loc. D3843-B, 13 ft above base of unit	52	0
2. Bentonite, grayish-yellow	2	0
1. Shale, grayish-black; slightly sandy in lower part. USGS Paleobotany loc. D3843-A, 5 ft above base of unit	20	0
Total thickness of black shale member	202	0
Total thickness of Mowry Shale	527	0
Lower Cretaceous—Newcastle Sandstone.		

FRONTIER FORMATION

One stratigraphic section of the Frontier Formation, section 10, is considered to be representative of the formation in the area west of Livingston. The section was measured on the north side of Canyon Mountain. This readily accessible section is here designated a reference section.

SECTION 10

Reference section of the Frontier Formation, measured on the north side of Canyon Mountain in secs. 26 and 27, T. 2 S., R. 9 E., Park County, Mont.

[Measured by A. E. Roberts and J. S. Hollingsworth, 1955]

	Ft	In.
Upper Cretaceous—Cody Shale.		
Upper Cretaceous—Frontier Formation:		
27. Sandstone, massive, micaceous, very fine to fine-grained, indurated, light-greenish-gray (5*GY* 7/1); weathers to medium light gray (*N*6) and contains reddish-brown specks of hematite; ridge former	8	0
26. Sandstone, thin-bedded, micaceous, very fine grained, gray	12	0
25. Shale, silty, dark-gray to black	4	0
24. Sandstone, thin-bedded, silty, micaceous, very fine grained, gray	15	0
23. Sandstone, thin- to medium-bedded, silty, very fine grained, micaceous, calcareous, indurated, light-greenish-gray (5*GY* 7/1); weathers to yellowish orange (10*YR* 7/6); ridge former	7	0
22. Sandstone, thin-bedded, silty, calcareous, carbonaceous, very fine grained, medium-gray	4	0
21. Siltstone, thin-bedded, carbonaceous, micaceous, medium-gray	19	0
20. Shale, silty, carbonaceous, micaceous, pyritic, dark-gray; contains streaks of siltstone	17	0
19. Siltstone, thin-bedded, calcareous, medium-light-gray	9	0
18. Sandstone, medium-bedded, silty, micaceous, carbonaceous, very fine to fine-grained, indurated, light-greenish-gray (5*GY* 8/1); weathers to light olive gray (5*Y* 6/1)	11	0
17. Shale, silty, dark-gray	1	0
16. Conglomerate; pebbles less than 2 in. in diameter of well-rounded chert in sand matrix; "C" bed on geologic maps (Roberts, 1964b, e, and f)	3	0
15. Sandstone, massive to crossbedded, yellowish-gray (5*Y* 8/1), poorly sorted, pebbly; prominent ridge former; weathers to dark yellowish-orange (10*YR* 6/6). Sand grains are chiefly quartz, feldspar, and gray or brown chert that are angular to subrounded	18	0
14. Siltstone, thin-bedded, indurated, dark-gray	31	0
13. Sandstone, medium-bedded, calcareous, feldspathic, glauconitic, very fine to fine-grained, gray; contains sporadic chert pebbles	9	0
12. Siltstone, thin- to medium-bedded, greenish-gray (5*GY* 6/1); weathers to yellowish gray (5*Y* 8/1)	12	0
11. Sandstone, thin- to medium-bedded, greenish-gray (5*GY* 6/1), very fine grained, indurated; ridge former; weathers to a mottled surface of yellowish gray (5*Y* 8/1) and light gray (*N*7); contains heavy-mineral suite concentrated in very thin bands	4	0

SECTION 10—Continued

Reference section of the Frontier Formation, measured on the north side of Canyon Mountain in secs. 26 and 27, T. 2 S., R. 9 E., Park County, Mont.—Continued

Upper Cretaceous—Frontier Formation—Continued	Ft.	In.
10. Sandstone, thick and crossbedded, light-gray (*N*7), very fine- to fine-grained, slightly calcareous; weathers to yellowish-gray (5*Y* 8/1); contains a heavy-mineral suite, commonly in dark bands 0.25 in. or less in thickness	2	0
9. Siltstone, platy to thin-bedded, feldspathic, glauconitic, grayish-olive (10*Y* 4/2) to olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2); contains a few interbeds of thin-bedded, very fine grained, calcareous sandstone and dark-grayish-brown carbonaceous shale that includes very thin beds of coal	70	0
8. Sandstone, thin- to thick-bedded, crossbedded, grayish-yellow-green (5*GY* 7/2), fine- to coarse-grained, micaceous, glauconitic, indurated; weathers to dark yellowish brown (10*YR* 4/2); contains a heavy-mineral suite; very prominent ridge former	30	0
7. Shale, silty, dark-brown; contains very thin beds of coal	10	0
Boulder River Sandstone Member:		
6. Sandstone, thin-bedded, mottled dark-gray (*N*3) and medium-light-gray (*N*6), very fine grained, feldspathic, micaceous; weathers to a mottled greenish gray (5*GY* 6/1) and very light gray (*N*8). Mottling due to crystal clusters of analcime in the cementing material. "A" bed on geologic maps (Roberts, 1964b, d–f, and h)	45	0
5. Sandstone, thin-bedded, silty, very fine grained, grayish-green; contains interbedded silty dark-grayish-brown shale	27	0
4. Sandstone, thin-bedded, grayish-olive-green (5*GY* 3/2), very fine grained, calcareous, micaceous; weathers to light olive gray (5*Y* 5/2) and contains reddish-brown specks	5	0
3. Sandstone, massive, light-gray (*N*7), very fine to fine-grained, poorly sorted; weathers to yellowish gray (5*Y* 7/2); calcareous and more indurated in upper 5 in.; contains a heavy-mineral suite; contains sporadic rounded dark-gray (*N*3) chert pebbles and a few small channel-fill deposits of chert pebbles and granule-size sand near top (fig. 9)	10	0
2. Sandstone, very thin bedded, grayish-yellow green (5*GY* 7/2), silty, very fine grained, calcareous, micaceous, glauconitic; weathers to light olive gray (5*Y* 6/1) and contains reddish-brown specks; contains *Inoceramus* sp.	8	0
1. Sandstone, thin- to thick-bedded, crossbedded, grayish-green (10*GY* 5/2), very fine to fine-grained, micaceous, glauconitic, feldspathic, calcareous, poorly sorted; weathers to brownish gray (5*YR* 4/1); contains heavy-mineral suite; contains a few interbeds of very thin to thin-bedded siltstone. Almost every bedding plane has a ripple-marked surface, and many have abundant casts and molds of *Ophiomorpha* and other burrows (fig. 10). A few poorly preserved plant fragments were also noted	24	0
Total thickness of Boulder River Sandstone Member	119	0
Total thickness of Frontier Formation	415	0

Lower Cretaceous—Mowry Shale.

CODY SHALE

The Cody Shale is not well exposed in the area west of Livingston. The most complete section was measured on the north side of Canyon Mountain, and descriptions of the covered intervals in this section were added from the Deerfield Oil Corp. Strong 1 well. The description of section 11 is considered to be typical of the formation for this area.

SECTION 11

Composite section of the Cody Shale, measured on the north side of Canyon Mountain in sec. 27, T. 2 S., R. 9 E., and adjusted with section of the Deerfield Oil Corp. Strong 1 well in sec. 11, T. 2 S., R. 9 E., Park County, Mont.

[Measured by A. E. Roberts, 1961]

Upper Cretaceous—Telegraph Creek Formation.

Upper Cretaceous—Cody Shale:	Ft	In.
Upper shale member:		
32. Siltstone, thin-bedded to massive, micaceous, calcareous, dark-gray to dark-brownish-gray	30	0
31. Sandstone, thin-bedded, silty, micaceous, calcareous, pyritic, very fine to fine-grained; contains thin interbedded dark-brownish-gray shale	24	0
30. Shale, calcareous, dark-brownish-gray; contains thin interbedded dark-gray siltstone	16	0
29. Sandstone, thin- to medium-bedded, silty, calcareous, pyritic, glauconitic, micaceous, very fine grained; contains thin interbedded calcareous dark-brownish-gray shale	40	0
28. Mudstone, thin-bedded to massive, silty, pyritic, dark-brownish-gray; contains thin interbedded calcareous siltstone	25	0
27. Sandstone, thin- to medium-bedded, silty, calcareous, pyritic, glauconitic, micaceous, very fine to fine-grained, gray; contains thin interbedded silty dark-brownish-gray shale; bears red specks of heulandite(?)	38	0

SECTION 11—Continued

Composite section of the Cody Shale, measured on the north side of Canyon Mountain in sec. 27, T. 2 S., R. 9 E., and adjusted with section of the Deerfield Oil Corp. Strong 1 well in sec. 11, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Upper Cretaceous—Cody Shale—Continued		
Upper shale member—Continued		
26. Mudstone, massive, silty, pyritic, dark-brownish-gray	12	0
25. Siltstone, thin- to medium-bedded, micaceous, pyritic, gray; contains thin interbedded silty dark-brownish-gray shale	19	0
24. Mudstone, massive, silty, calcareous, micaceous, pyritic, dark-brownish-gray	21	0
23. Sandstone, thin- to medium-bedded, fine- to coarse-grained, subrounded grains, light-gray	10	0
22. Shale, silty, calcareous, pyritic, dark-grayish-brown; contains thin interbedded siltstone	24	0
21. Sandstone, thin- to medium-bedded, calcareous, glauconitic, micaceous, very fine grained; contains thin interbedded silty, calcareous, dark-grayish-brown shale	22	0
20. Mudstone, thin- to thick-bedded, silty, calcareous, sideritic, pyritic, dark-grayish-brown; contains thin interbedded, fine- to coarse-grained, quartzose, light-gray sandstone that bears subrounded grains	43	0
19. Sandstone, thin-bedded, silty, calcareous, pyritic, micaceous, very fine to fine-grained, gray; contains interbedded silty, dark-grayish-brown shale	21	0
18. Siltstone, thin-bedded, sandy, calcareous, micaceous, sideritic, gray	10	0
17. Shale, pyritic, dark-gray to dark-brownish-gray; contains thin interbedded gray siltstone	50	0
16. Siltstone, thin-bedded, sandy, calcareous, micaceous, sideritic, gray; contains interbedded dark-gray shale	15	0
15. Sandstone, medium-bedded, silty, calcareous, micaceous, very fine grained, white	5	0
14. Shale, silty, calcareous, pyritic, micaceous, dark-gray; contains thin, interbedded, calcareous, gray siltstone	150	0
Total thickness of upper shale member	575	0
Eldridge Creek Member:		
13. Sandstone, platy to thin-bedded, silty, calcareous, very glauconitic, micaceous, pyritic, very fine grained, greenish-gray; weathers to grayish yellow green; contains thin interbedded calcareous siltstone and silty, calcareous, dark-brownish-gray shale; fossiliferous; USGS Mesozoic loc. D581; slight ridge former (fig. 11)	120	0
Total thickness of Eldridge Creek Member	120	0
Lower shale member:		
12. Shale, silty, calcareous, micaceous, pyritic, dark-brownish-gray; contains thin interbedded very fine grained sandstone and siltstone	90	0
11. Shale, silty, calcareous, micaceous, pyritic, glauconitic, dark-grayish-brown; contains lenses of gray siltstone	75	0
10. Siltstone, thin-bedded, shaly, calcareous, micaceous, pyritic, glauconitic, gray; contains thin interbedded dark-gray, silty shale	130	0
9. Shale, silty, calcareous, micaceous, glauconitic, dark-brownish-gray; contains thin interbedded, very fine grained, calcareous, gray sandstone and siltstone; calcareous concretions (commonly septarian)	65	0
8. Siltstone, thin-bedded, clayey, calcareous, micaceous, glauconitic, dark-grayish brown	10	0
7. Shale, silty, micaceous, pyritic, dark-gray	20	0
6. Shale, silty, calcareous, micaceous, pyritic, dark-gray; contains thin interbedded very fine grained, silty, calcareous sandstone	30	0
5. Shale, silty, micaceous, pyritic, dark-brownish-gray; contains thin interbedded calcareous siltstone; fossiliferous; bentonite bed near middle of unit	100	0
4. Sandstone, medium-bedded, conglomeratic, calcareous, micaceous, very fine to coarse-grained; contains pebbles of well-rounded chert	4	0
3. Shale, silty, calcareous, micaceous, pyritic, dark-grayish-brown	6	0
2. Sandstone, medium-bedded, indurated, very fine grained, light-greenish-gray; weathers to yellowish orange; contains heavy-mineral suite including much biotite; ridge former	5	0

SECTION 11—Continued

Composite section of the Cody Shale, measured on the north side of Canyon Mountain in sec. 27, T. 2 S., R. 9 E., and adjusted with section of the Deerfield Oil Corp. Strong 1 well in sec. 11, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Upper Cretaceous—Cody Shale—Continued		
Lower shale member—Continued		
1. Shale, silty, calcareous, micaceous, pyritic, dark-gray to dark-brownish-gray; contains thin interbedded calcareous gray siltstone; bentonite bed near middle of unit	55	0
Total thickness of lower shale member	590	0
Total thickness of Cody Shale	1, 285	0
Upper Cretaceous—Frontier Formation.		

TELEGRAPH CREEK FORMATION

Two stratigraphic sections of the Telegraph Creek Formation are considered to be representative of the formation in the area west of Livingston. These are measured section 12, near the abandoned townsite of Cokedale, Mont., and measured section 13, on the north side of Canyon Mountain. The sequence at Cokedale is siltstone and sandstone at a ratio of approximately three to one. The sequence at Livingston is approximately a third of shale and mudstone and two-thirds of siltstone and sandstone.

SECTION 12

Telegraph Creek Formation, measured in the NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.

[Measured by A. E. Roberts and J. S. Hollingsworth, 1955]

	Ft	In.
Upper Cretaceous—Eagle Sandstone.		
Upper Cretaceous—Telegraph Creek Formation:		
10. Sandstone, thin-bedded (0.5 in. or less), light-gray (*N*7), fine-grained, quartzose, very calcareous; weathers to yellowish gray (5*Y* 7/2); contains heavy-mineral suite; has salt-and-pepper appearance. Unit is very uniform throughout	43	0
9. Siltstone, thin-bedded to massive, sandy; contains thin interbedded, very fine grained, quartzose sandstone. This unit is poorly exposed. Siltstone is generally mottled olive gray (5*Y* 4/1) and dark greenish gray (5*GY* 4/1), is generally carbonaceous, contains disseminated plant fragments, and weathers to pale olive (10*Y* 6/2). Unit resembles a brackish-water tidal-flat deposit. Sandstone is very minor, 5 percent estimate, and is thin bedded (0.5 in. or less) and generally very calcareous	78	0
8. Siltstone, massive, medium-dark-gray (*N*4), slightly carbonaceous; weathers to a yellowish gray (5*Y* 7/2); very calcareous	29	0

SECTION 12—Continued

Telegraph Creek Formation, measured in the NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

	Ft	In.
Upper Cretaceous—Telegraph Creek Formation—Con.		
7. Sandstone, thin-bedded to massive, very fine grained, very calcareous, light-gray (*N*7), quartzose, indurated; contains some disseminated plant fragments; contains heavy-mineral suite; ripple marked; weathers to yellowish gray (5*Y* 7/2). Worm(?) tubes noted on bedding surfaces	4	0
6. Siltstone, thin-bedded, olive-gray (5*Y* 4/1), slightly carbonaceous, very calcareous; contains some disseminated plant fragments; weathers to yellowish gray (5*Y* 7/2)	23	0
5. Sandstone, thin-bedded, light-olive-gray (5*Y* 6/1), very calcareous, indurated, very fine grained, quartzose; weathers to yellowish gray (5*Y* 7/2)	4	0
4. Siltstone, thin-bedded, (bedding is 0.5 in. thick or less), olive-gray (5*Y* 4/1), slightly carbonaceous, very calcareous; contains disseminated plant fragments; weathers to yellowish gray (5*Y* 7/2)	5	0
3. Sandstone, thick-bedded, very calcareous, very fine grained, light-olive-gray (5*Y* 6/1), indurated, quartzose. Pronounced spheroidal weathering in large concentric sheets. The unit is continuous, but the spheroidal weathering makes it appear concretionary	3	0
2. Siltstone, thin-bedded, olive-gray (5*Y* 4/1), slightly carbonaceous, very calcareous; weathers to yellowish gray (5*Y* 7/2)	16+	0
1. Concealed; probably thin-bedded siltstone and fine-grained sandstone	70	0
Total thickness of Telegraph Creek Formation	275	0
Upper Cretaceous—Cody Shale.		

SECTION 13

Composite section of the Telegraph Creek Formation, measured on the north side of Canyon Mountain in sec. 27, T. 2 S., R. 9 E.; and adjusted with the section of the Deerfield Oil Corp. Strong 1 well in sec. 11, T. 2 S., R. 9 E., Park County, Mont.

[Measured by A. E. Roberts, 1961]

	Ft	In.
Upper Cretaceous—Eagle Sandstone.		
Upper Cretaceous—Telegraph Creek Formation:		
11. Siltstone, thin-bedded, sandy, micaceous, pyritic, sideritic, medium-gray; contains interbedded shale	40	0
10. Sandstone, thin-bedded, silty, micaceous, pyritic, very fine grained	15	0
9. Siltstone, massive, sandy, micaceous, calcareous, pyritic, dark-gray; contains thin interbedded shale and very fine grained sandstone beds	40	0
8. Mudstone, massive, micaceous, sandy, calcareous, dark-brownish-gray	15	0
7. Sandstone, thin-bedded, silty, micaceous, pyritic, calcareous, very fine to medium-grained, gray; contains interbedded shale	30	0

SECTION 13—Continued

Composite section of the Telegraph Creek Formation, measured on the north side of Canyon Mountain in sec. 27, T. 2 S., R. 9 E.; and adjusted with the section of the Deerfield Oil Corp. Strong 1 well in sec. 11, T. 2 S., R. 9 E., Park County, Mont.—Con.

Upper Cretaceous—Telegraph Creek Formation—Con.	Ft	In.
6. Shale, silty, micaceous, pyritic, calcareous, dark-brownish-gray; contains thin interbedded very fine grained sandstone	20	0
5. Sandstone, thin-bedded, silty, sideritic, feldspathic, very fine grained, gray	8	0
4. Mudstone, thin-bedded to massive, silty, sideritic, calcareous, light-gray to gray and green; contains interbedded calcareous siltstone	42	0
3. Sandstone, thin-bedded, calcareous, pyritic, very fine grained, light-gray; contains abundant heavy minerals and thin, interbedded, calcareous, silty shale	43	0
2. Shale, silty, calcareous, dark-gray and brownish-gray	12	0
1. Sandstone, thin- to thick-bedded, silty, calcareous, feldspathic, micaceous, pyritic, sideritic, very fine to fine-grained, light-gray; contains abundant heavy minerals	30	0
Total thickness of Telegraph Creek Formation	295	0

Upper Cretaceous—Cody Shale.

EAGLE SANDSTONE

Two stratigraphic sections of the Eagle Sandstone are considered to be typical of the formation in the area west of Livingston. These are measured section 14, near the abandoned townsite of Cokedale, Mont., and section 15, measured near Livingston, Mont., on the west side of the Yellowstone River. Comparison of these two stratigraphic sequences indicates that the sandstone has an eastward decrease in average grain size and that the formation has an eastward decrease in coal content and in thickness.

SECTION 14

Reference section of the Eagle Sandstone, measured on the north side of Miner Creek in the NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.

[Measured by Albert E. Roberts and J. Stewart Hollingsworth in 1955]

Cokedale Formation (Upper Cretaceous).

Eagle Sandstone (Upper Cretaceous):	in.	Ft	in
104. Sandstone, thick-bedded, indurated (slight ridge former), calcitic, very fine grained, light-olive-gray (5*Y* 6/1), arkosic. Weathers to pale-olive (10*Y* 6/2) slabs about 3–6 in. thick. Sorting, fair. Quartz grains comprise 50 percent. Contains heavy-mineral suite		3	0
103. Siltstone, thick-bedded, tuffaceous, olive-gray (5*Y* 4/1), and thin interbedded very fine grained sandstone Weathers to dusky yellow (5*Y* 6/4). Contains fragments (fine grained) of volcanic rocks and plant fragments. Unit poorly exposed		2	0
102. Siltstone, very carbonaceous, tuffaceous, clayey (roof)		5	0
101. Coal (Cokedale coal bed or locally the Cokedale No. 5 bed), attitude N. 84° W., 40° NE		5	0
Siltstone, very carbonaceous, tuffaceous	2		
Siltstone, tuffaceous	1		
Bone	3		
Coal	8		
Siltstone, altered, tuffaceous, carbonaceous	2.5		
Coal	11		
Siltstone, altered, tuffaceous, carbonaceous	.5		
Bone	5		
Coal	19		
Bone	2		
Siltstone, very carbonaceous, clayey	6		
100. Siltstone, massive, light-gray (*N*7), clayey. Poorly exposed. Weathers to light-olive-gray (5*Y* 6/1) soil		6	0
99. Sandstone, indurated (slight ridge former), very fine grained, dusky-yellow-green (5*GY* 5/2). Sorting, fair. Weathers to yellowish orange (10*YR* 7/6). Rock appears to be transition of Eagle Sandstone and Livingston Group lithologies. Weathers along fractures (N. 60° W.) and bedding planes. Attitude N. 80° W., 40° NE		2	0
98. Siltstone, thick-bedded, light-olive-gray (5*Y* 6/1), clayey, carbonaceous. Weathers to moderate yellowish brown (10*YR* 5/4). Small granule-size grains near base		3	0
97. Coal (probably Paddy Miles coal bed or locally the Cokedale No. 4 bed)		1	0
Bone	3		
Coal	9		
96. Siltstone, medium-bedded, olive-gray (5*Y* 4/1). Weathers to moderate yellowish brown (10*YR* 5/4)		1	6
95. Siltstone, very carbonaceous (almost bone)			2
94. Siltstone, massive, pale-olive (10*Y* 6/2), tuffaceous. Weathers to moderate greenish yellow (10*Y* 7/4). Forms a crumbly soil		4	0
93. Sandstone, indurated, slabby, crossbedded, very fine grained, yellow-green (5*GY* 6/2); slight ridge former. Irregular thickness, from 4 to 6 ft		5	0

Reference section of the Eagle Sandstone, measured on the north side of Miner Creek in the NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	in.	Ft	In.
92. Siltstone, massive, olive-gray (5*Y* 4/1), carbonaceous. Poorly exposed		13	0
91. Siltstone, thick-bedded, medium-dark-gray (*N*4), carbonaceous. Weathers to light olive gray (5*Y* 6/1). Slightly more indurated than overlying siltstone. Breaks with conchoidal fracture. Manganese stain common on fracture surfaces. Spheroidal weathering		2	0
90. Coal, probably Storrs No. 3 coal bed (upper part); not described, as bed is burned along the outcrop from the valley to top of the hill		2	0
89. Siltstone, very carbonaceous, grayish-brown (5*YR* 3/2), weathers to pale yellowish brown (10*YR* 6/2). Contains plant fragments		1	0
88. Siltstone, massive, greenish-gray (5*GY* 6/1). Weathers to yellowish gray (5*Y* 8/1). Poorly exposed		6	0
87. Coal, probably Storrs No. 3 coal bed (lower part)		2	0
Bony coal	1		
Coal	8		
Siltstone, very carbonaceous	3		
Coal	8		
Bony coal	1		
Siltstone, very carbonaceous	3		
86. Siltstone, massive, light-olive-gray (5*Y* 6/1), tuffaceous; weathers to yellowish gray (5*Y* 8/1). Poorly exposed		11	0
85. Sandstone, massive, very light gray (*N*8), fine-grained, arkosic. "Salt-and-pepper" appearance. Contains heavy-mineral suite. Somewhat porous; considerable limonitic staining near top of unit. Slightly crossbedded. Sorting, fair. Massive spheriodal weathering. Weathers to yellowish gray (5*Y* 7/2)		6+	0
84. Concealed; probably fine-grained very light gray arkosic sandstone		36	6
83. Sandstone, massive, very light gray (*N*8), fine-grained, arkosic. "Salt-and-pepper" appearance. Contains heavy-mineral suite. Sorting, fair. Massive spheroidal weathering. Weathers to yellowish gray (5*Y* 7/2)		18+	0
82. Sandstone, massive, slabby, arkosic, calcareous, mixture of very fine grained sand and pods or lenses of silt (definite brackish-water deposit), yellowish-gray (5*Y* 7/2). Mottled where silt is concentrated. Weathers to grayish yellow (5*Y* 8/4). Many worm tubes or pelecypod burrowings (some 12 in. long)		15	0
81. Siltstone, thick-bedded, mottled, yellowish-gray (5*Y* 7/2), sandy. Brackish-water deposit. Weathers to grayish yellow (5*Y* 8/4)		2	0

Reference section of the Eagle Sandstone, measured on the north side of Miner Creek in the NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	in.	Ft	In.
80. Sandstone, thick-bedded, indurated, very fine grained, arkosic, very calcareous, light-olive-gray (5*Y* 6/1). Weathers to yellowish gray (5*Y* 7/2). Contains heavy-mineral suite		3	0
79. Sandstone, massive, poorly consolidated, light-greenish-gray (5*GY* 8/1), fine-grained to very fine grained, arkosic. Very poorly exposed. Weathers to yellowish gray (5*Y* 7/2)		4	0
78. Sandstone, massive, indurated, fine-grained, calcareous, light-gray (*N*7), arkosic. Weathers to yellowish gray (5*Y* 7/2). Contains heavy-mineral suite. Vertical worm tubes. Little banding along indistinct bedding planes noted in middle of unit		5	0
77. Sandstone, thick-bedded, fine-grained, poorly indurated, very light gray (*N*8), arkosic. Weathers to yellowish gray (5*Y* 8/1)		2	0
76. Sandstone, massive, fine-grained, light-olive-gray (5*Y* 6/1), indurated, calcareous, arkosic. Weathers to light brown (5*YR* 6/4). Conspicuously jointed N. 75°–85° W. normal to base of bed. Lower 1–2 ft shows faint, indistinct bedding. A few worm tubes(?) associated with irregular lenses and pods of poorly sorted mottled sandy siltstone		12	0
75. Sandstone and siltstone, thin-bedded, light-olive-gray (5*Y* 6/1), arkosic, indurated, calcareous (very calcareous in lower half), very fine grained; weathers to yellowish gray (5*Y* 7/2). Contains heavy-mineral suite		2	0
Siltstone	4		
Sandstone	7		
Siltstone	2		
Sandstone	7		
Siltstone	4		
74. Sandstone, indurated, very fine gained, light-gray (*N*7), arkosic, very calcareous. Weathers to yellowish gray (5*Y* 7/2). Contains heavy-mineral suite. Sorting, fair. Attitude N. 75° W., 39° NE		1	0
73. Siltstone, light-olive-gray (5*Y* 6/1), calcareous. Weathers to yellowish gray (5*Y* 7/2)			6
72. Sandstone, platy, light-gray (*N*7), arkosic, fine-grained, calcareous. Weathers to yellowish-gray (5*Y* 7/2) thin sheets (½ in. or less thick). Contains a heavy-mineral suite that is banded along many bedding planes like varves		6	0
71. Sandstone, medium-bedded, very fine grained, light-olive-gray (5*Y* 6/1), silty, poorly sorted, carbonaceous, arkosic, slightly calcareous; contains calcareous lenses 1 ft thick. Weathers to yellowish			

Reference section of the Eagle Sandstone, measured on the north side of Miner Creek in the NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	*Ft*	*In.*
gray (5Y 7/2). Contains macerated plant fragments and heavy minerals	1	6
70. Sandstone, massive, very fine grained, light-olive-gray (5Y 6/1), arkosic, very calcareous. Weathers to yellowish gray (5Y 7/2). Contains a few plant fragments and heavy minerals. Poorly developed spheroidal weathering	5	0
69. Siltstone, platy (⅛ in. or less), olive-gray (5Y 4/1), slightly carbonaceous, very calcareous. Weathers to yellowish gray (5Y 7/2)	1	0
68. Sandstone, platy, very fine grained, light-olive-gray (5Y 6/1), arkosic, very calcareous, indurated. Weathers to light olive gray (5Y 5/2). Contains heavy-mineral suite	2	0
67. Siltstone, very carbonaceous		3
66. Sandstone, massive, poorly indurated (except for very calcareous pods and lenses), poorly sorted, silty, very fine grained, arkosic, pale-olive (10Y 6/2); contains very calcareous pods and lenses. In places, mottled by concentration of silt. Typical of brackish-shallow-water deposit. Contains plant fragments and heavy minerals	5+	0
65. Concealed; probably thin-bedded very fine grained arkosic sandstone. Considerable sandstone float for this interval	6	0
64. Sandstone, thin-bedded, light-olive-gray (5Y 6/1), fine-grained, arkosic, calcareous. Bedding <¼ in. thick, marked by bands of heavy minerals. Weathers to yellowish-gray (5Y 7/2) ½–2-in. slabs. Contains disseminated plant fragments. Attitude N. 84° W., 41° NE	2	0
63. Sandstone, thin-bedded, silty, very fine grained, arkosic, calcareous, light-olive-gray (5Y 6/1). Weathers to yellowish gray (5Y 7/2). Less indurated than overlying sandstone. Base not exposed	4+	0
62. Concealed; probably thin-bedded silty very fine grained sandstone	23	0
61. Sandstone, thin-bedded, light-olive-gray (5Y 6/1), indurated (slight ridge former), very fine grained, calcareous. Weathers to yellowish-gray (5Y 6/2) slabs ½–2 in. thick. Contains plant fragments and heavy-mineral suite	2+	0
60. Concealed; probably thin-bedded silty very fine grained sandstone	12	0
59. Sandstone, platy, light-olive-gray (5Y 6/1), calcareous, arkosic, very fine grained. Weathers to slabs about ½ in. thick. Contains heavy-mineral suite and plant fragments—one fair quality leaf impression noted. Attitude N. 89° W., 42° NE	4	0
58. Concealed; probably thin-bedded silty very fine grained sandstone	4	0

Reference section of the Eagle Sandstone, measured on the north side of Miner Creek in the NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	*Ft*	*In.*
57. Sandstone, platy, light-olive-gray (5Y 6/1), calcareous, arkosic, very fine grained. Weathers to slabs about ½ in. thick. Contains heavy-mineral suite and plant fragments	4	0
56. Concealed; probably thin-bedded silty very fine grained sandstone	8	0
55. Sandstone, platy, indurated (slight ridge former), calcareous, arkosic, very fine grained, light-olive-gray (5Y 6/1). Angular to subangular grains. Sorting, fair. Crossbedded. Weathers to yellowish gray (5Y 7/2). Few poorly preserved leaf impressions. Calcite veinlets <¼ in. thick along fracture surfaces	2	0
54. Concealed; probably thin-bedded silty very fine grained sandstone	20	0
53. Sandstone, platy, indurated (slight ridge former), calcareous, arkosic, very fine grained, light-olive-gray (5Y 6/1). Angular to subangular grains. Sorting, fair. Crossbedded. Weathers to yellowish gray (5Y 7/2)	3	0
52. Concealed; probably thin-bedded silty very fine grained sandstone	8	0
51. Sandstone, platy, indurated, calcareous, arkosic, very fine grained, light-olive-gray (5Y 6/1). Weathers to yellowish gray (5Y 7/2). Attitude N. 83° W., 49° NE	3	0
50. Concealed; probably thin-bedded silty very fine grained sandstone	17	0
49. Sandstone, platy, indurated (slight ridge former), calcareous, arkosic, very fine grained, light-olive-gray (5Y 6/1). Angular to subangular grains. Sorting, fair. Crossbedded. Weathers to yellowish gray (5Y 7/2)	3	0
48. Concealed; probably thin-bedded silty very fine grained sandstone	12	0
47. Sandstone, platy, indurated (slight ridge former), calcareous, arkosic, very fine grained, light-olive-gray (5Y 6/1). Angular to subangular grains. Sorting, fair. Crossbedded. Weathers to yellowish gray (5Y 7/2)	2	0
46. Concealed; probably thin-bedded silty very fine grained sandstone	4	0
45. Sandstone, platy, indurated (slight ridge	5	
former), calcareous, arkosic, very fine grained, light-olive-gray (5Y 6/1). Angular to subangular grains. Sorting, fair. Crossbedded. Weathers to yellowish gray (5Y 7/2). Large very calcareous olive-gray (5Y 5/1) concretionary lenses of sandstone (some as large as 2×5 ft). They weather to yellowish gray (5Y 6/2) with pronounced spheroidal weathering	4	0
44. Sandstone, platy, slightly indurated, arkosic, calcareous, very fine grained, light-olive-gray (5Y 6/1); interbedded thin-bedded silty very fine grained sandstone. Weathers to yellowish gray (5Y 6/2)	14	0

786-073 O-66—2

Reference section of the Eagle Sandstone, measured on the north side of Miner Creek in the NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	Ft	In.
43. Sandstone, thin- to medium-bedded, indurated (slight ridge former), calcerous, very fine grained, arkosic, light-olive-gray (5*Y* 6/1). Angular to subangular grains. Sorting, fair. Weathers to yellowish gray (5*Y* 6/2)	2	6
42. Sandstone, thin-bedded, silty, very fine grained, light-olive-gray (5Y 6/1). Weathers to yellowish gray (5*Y* 6/1). Poorly exposed	2	6
41. Tuff, microlitic, medium-bedded, medium-dark-gray (*N*4), indurated, silty, very fine grained, calcareous (few small secondary calcite crystals), andesitic. Angular grains. Poorly sorted. Weathers to olive gray (5*Y* 3/1). Rock composed mostly of volcanic rock fragments and plagioclase (andesine). Many vugs $<1/4$ in. in diameter. Attitude N. 68° W., 38° NE	1	0
40. Sandstone, thick-bedded, dark-greenish-gray (5*GY* 4/1), poorly sorted, silty, medium-grained, angular grains, slightly calcareous, andesitic. Composed of volcanic rock fragments and plagioclase. Weathers to greenish gray (5*GY* 6/1). Faint, poorly formed bedding. Poorly sorted	3	0
39. Siltstone, massive, tuffaceous, light-olive-gray (5*Y* 5/2). Contains disseminated plant fragments. Weathers to yellowish gray (5*Y* 7/2)	4	0
Possible fault of less than a few feet displacement.		
38. Tuff, microlitic, massive, calcareous, medium-light-gray (*N*6), indurated, very fine grained, andesitic. Angular grains. Poorly sorted. Breaks with conchoidal fracture. Composed of volcanic rock fragments and plagioclase (too altered for composition determination). Weathers to dark yellowish brown (10*YR* 4/2). Many small vugs—some coated first with calcite and later with silica	4	0
37. Coal (Middle coal bed or locally the Cokedale No. 3 bed)	1	0
in.		
Coal — 5		
Siltstone, carbonaceous — 1		
Bone — 2		
Siltstone, very carbonaceous — 2		
Siltstone, carbonaceous — 2		
36. Sandstone, indurated, thin- to medium-bedded, fine-grained, slightly arkosic, yellowish-gray (5*Y* 7/2). Contains heavy-mineral suite. Weathers to yellowish brown (10*YR* 5/2)	1	0
35. Siltstone, poorly exposed, carbonaceous	3	0
34. Sandstone, thin-bedded to massive, yellowish-gray (5*Y* 7/2), slightly arkosic, very fine grained, very calcareous. Weathers to yellowish gray (5*Y* 6/2)	12	0
33. Siltstone, platy, greenish-gray (5*GY* 6/1), sandy. Contains disseminated plant fragments. Weathers to yellowish gray (5*Y* 8/1)	7	0
32. Coal (Maxey coal bed or locally the Cokedale No. 2 bed)	6	0
Ft		
Siltstone, very carbonaceous, with coaly streaks (almost bone) — 1		
Siltstone, very carbonaceous, approaches character of coal bed. Many tuffaceous siltstone partings — 5		
31. Sandstone, platy, carbonaceous, light-olive-gray (5*Y* 5/1), very calcareous, silty, very fine grained, arkosic. Weathers to grayish-yellow (5*Y* 7/4) slabs ½–2 in. thick. Few plant fragments. Attitude N. 89° W., 35° NE	5	0
30. Sandstone, very massive (cliff former directly opposite Miner Creek junction), light-gray (*N*7), fine-grained, crossbedded, arkosic. Good heavy-mineral suite. Calcareous. Massive spheroidal weathering. Weathers to grayish yellow (5*Y* 7/4). Unit lenses out eastward and westward and does not occur behind the coke ovens. Large plant fragments (some several feet across) and several beds of oysters near middle of unit on east side. Many intraformational breccias about 1–2 ft thick	42	0
29. Siltstone, platy, carbonaceous, sandy; calcareous concretions <3 in. diameter, dark yellowish brown (10*YR* 4/2), moderate yellowish brown (10*YR* 5/4). Carbonized plant fragments. Poorly exposed. Immediately east of section this unit becomes very carbonaceous (almost characteristic of coal bed)	2	0
28. Sandstone, massive to thin-bedded, light-olive-gray (5*Y* 6/1), very fine grained, indurated, calcareous, slightly carbonaceous. Contains heavy-mineral suite. In places, resembles brackish-water deposition. Weathers to yellowish gray (5*Y* 8/1). Unit thins abruptly eastward. Contains leaf impressions. A few vertical worm tubes	18	0
27. Siltstone, massive, greenish-gray (5*GY* 6/1); poorly exposed	5	0
26. Siltstone, very carbonaceous, with coaly streaks	1	0
25. Siltstone, massive, dark-greenish-gray (5*GY* 4/1). Contains disseminated plant fragments. Limonitic concretions noted. Weathers to light olive gray (5*Y* 6/1)	5	7
24. Siltstone, bone, and streaks of coal, very carbonaceous. Many carbonaceous, tuffaceous, sandy siltstone partings (as much as 3 in. thick, generally <2 in.). Just east of section the unit is cut out by a fault. Behind the coke ovens this unit is		

Reference section of the Eagle Sandstone, measured on the north side of Miner Creek in the NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	Ft	In.
approximately the same thickness. Much of the adjustment during the orogeny of folding and thrusting was taken up in the coal and siltstone beds, which display considerable shearing and many tight folds that do not occur in overlying and underlying resistant sandstones. There are undoubtedly many bedding-plane faults as indicated by bedding-plane shears. Many partings now have a boudinagelike structure. Some carbonaceous siltstone beds contain macerated plant fragments. This unit correlates with the Big Dirty coal bed or, locally, the Cokedale No. 1 bed	46	0
Total Eagle Sandstone above Virgelle Member	535	0
Virgelle Sandstone Member:		
23. Sandstone, massive, indurated (cliff former), generally noncalcareous, very light gray (*N*8), fine-grained, arkosic. Although very massive, bedding can be delineated by dark ⅛–1⁄16-in. bands of heavy minerals. Unit is almost entirely crossbedded. Crossbedding is generally 2–3 ft long, or less, and generally truncated. Massive spheroidal weathering. Weathers to yellowish gray (5*Y* 7/2). Contains a few channel-fill deposits of pebbles and cobbles of siltstone	25	6
22. Sandstone, medium-bedded, fine-grained, light-olive-gray (5*Y* 5/2), calcareous, arkosic. Weathers to moderate yellowish brown (10*YR* 5/4)	1	0
21. Sandstone, medium-bedded, very poorly sorted, olive-gray (5*Y* 4/1), fine- to medium-grained, noncalcareous; derived from volcanic rock. Bottom 5 in. is olive-black (5*Y* 2/1) tuffaceous siltstone. Entire unit contains many small channel-fill deposits of silt and sand	1	0
20. Sandstone, massive, generally noncalcareous, very light gray (*N*8), fine-grained, arkosic. Less indurated than overlying units	4	0
19. Sandstone, massive, indurated, generally noncalcareous, very light gray (*N*8), fine-grained, arkosic. Siltstone-pebble conglomerate generally at base	8	0
18. Sandstone, thin-bedded (½–4 in. thick), indurated, calcareous, greenish-gray (5*GY* 6/1), very fine grained, arkosic. Weathers to olive gray (5*Y* 4/1). Has 2-in. siltstone both in middle and at base of unit	1	6
17. Sandstone, medium-bedded, calcareous, very light gray (*N*8), fine- to medium-grained, arkosic. Contains abundant heavy-mineral suite. Many small channel-fill deposits of siltstone pebbles. Bed is irregular in thickness and generally crossbedded. Angular to subrounded grains. Sorting, fair. Weathers to yellowish gray (5*Y* 7/2)	1	0
16. Sandstone, medium-bedded, indurated, calcareous, greenish-gray (5*GY* 6/1), very fine grained, arkosic. Weathers to olive gray (5*Y* 4/1)	1	0
15. Sandstone, medium-bedded, very light gray, fine-grained, arkosic. Contains calcareous pods or lenses. Crossbedded. A few plant fragments. Contains heavy-mineral suite. Poorly sorted; some small channel-fill deposits of coarse-grained sandstone	2	0
14. Sandstone, poorly sorted, very fine grained, dark-greenish-gray (5*GY* 4/1), noncalcareous, andesitic. Crossbedded. Weathers to light olive gray (5*Y* 5/2)	1	0
13. Siltstone, thin-bedded, olive-gray (5*Y* 4/1). Weathers to light olive gray (5*Y* 5/2). Contains disseminated plant fragments		6
12. Sandstone, massive, very poorly sorted, coarse-grained, pale-olive (10*Y* 6/2) Weathers to yellowish gray (5*Y* 7/2). Contains sporadic pebbles of siltstone. Contains 4-in. olive-gray siltstone bed in middle of unit	4	0
11. Sandstone, medium-bedded, indurated, calcareous, fine-grained, pale-olive (10*Y* 6/2). Weathers to yellowish gray (5*Y* 7/2)	1	0
10. Sandstone, thick-bedded, very light gray, fine-grained, arkosic	3	0
9. Transition to overlying sandstone	1	0
8. Sandstone, indurated, olive-gray (5*Y* 4/1), very fine grained, andesitic. Weathers to dark yellowish brown (10*YR* 4/2). Noncalcareous		6
7. Transition from underlying sandstone	1	0
6. Sandstone, massive, very light gray, fine-grained, arkosic	4	0
5. Sandstone, medium-bedded, poorly sorted, very fine grained, andesitic, dusky-yellow-green (5*GY* 5/2). Weathers to moderate yellowish brown (10*YR* 5/4)	1	0
4. Sandstone, medium-bedded, poorly sorted, medium- to coarse-grained, very light gray (*N*8), arkosic, crossbedded. Weathers to yellowish gray (5*Y* 7/2)	1	0
3. Sandstone, medium-bedded, very light gray, fine-grained, arkosic	1	0
2. Sandstone, platy, very light gray (*N*8), indurated, calcareous, fine-grained, arkosic, with thin (2 in. or less) stringers of coarse-grained sandstone. Crossbedded in part. Weathers to olive gray (5*Y* 4/1)	2	0
1. Sandstone, massive, very light gray (*N*8), fine-grained, arkosic, slightly calcareous, crossbedded. Contains quartz, orthoclase, andesine, heavy minerals, and fragments of andesite. Contains many vertical worm(?) tubes. Cliff-former. 4-ft zone of very poorly sorted sandstone containing silt		

Reference section of the Eagle Sandstone, measured on the north side of Miner Creek in the NW¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

	Ft	In.
Eagle Sandstone (Upper Cretaceous)—Continued		
Virgelle Sandstone Member—Continued		
that gives rock a mottled appearance 4 ft from top of unit. Massive spheroidal weathering. Angular to subrounded grains. Sorting, fair. Weathers to yellowish gray (5*Y* 7/2)	44	0
Total thickness of Virgelle Sandstone Member	110	0
Total thickness of Eagle Sandstone	645	0

Telegraph Creek Formation.

SECTION 15

Composite section of the Eagle Sandstone, measured on west side of the Yellowstone River in the NE¼ sec. 27, T. 2 S., R. 9 E., and adjusted with section of the Deerfield Oil Corp. Strong 1 well in SW¼ sec. 11, T. 2 S., R. 9 E., Park County, Mont.

[Measured by Albert E. Roberts in 1961]

	Ft	in
Cokedale Formation (Upper Cretaceous)		
Eagle Sandstone (Upper Cretaceous):		
28. Sandstone, medium-bedded, feldspathic, micaceous, fine- to medium-grained, light-olive-gray; rounded to subrounded grains; contains heavy-mineral suite and chert grains	2	0
27. Siltstone, thin- to medium-bedded, carbonaceous, olive-gray; thin interbedded coal beds (correlates with Cokedale coal bed)	8	0
26. Sandstone, medium- to thick-bedded, calcareous, micaceous, volcanic rock fragments, dusky-yellow-green; transition of Eagle Sandstone and Livingston Group lithologies; angular grains. Thin coal bed near middle of unit (correlates with Paddy Miles coal bed)	24	0
25. Shale, massive, silty, pyritic, pale-olive	20	0
24. Sandstone, thick-bedded, calcareous, very fine grained to fine-grained, yellow-green; angular grains	16	0
23. Siltstone, thin-bedded, olive-gray; thin interbedded olive-gray shale	45	0
22. Shale, thin-bedded, sandy, carbonaceous, gray; contains abundant orange (heulandite(?)) specks	10	0
21. Sandstone, medium-bedded, calcareous, micaceous, pyritic, medium- to coarse-grained, very light gray; contains heavy-mineral suite	8	0
20. Shale, massive, silty, pyritic, olive-gray	22	0
19. Sandstone, medium-bedded, silty, calcareous, micaceous, very fine grained, light-gray; contains heavy-mineral suite	10	0
18. Shale, massive, sandy, olive-gray; contains abundant orange (heulandite(?)) specks; thin interbedded olive-gray siltstone	18	0
17. Sandstone, thick-bedded, calcareous, micaceous, medium- to coarse-grained, very light gray; contains heavy-mineral suite	27	0

Composite section of the Eagle Sandstone, measured on west side of the Yellowstone River in the NE¼ sec. 27, T. 2 S., R. 9 E., and adjusted with section of the Deerfield Oil Corp. Strong 1 well in SW¼ sec. 11, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Eagle Sandstone (Upper Cretaceous)—Continued		
16. Sandstone, thin- to medium-bedded, silty, calcareous, micaceous, very fine grained to fine-grained, very light gray; contains heavy-mineral suite	10	0
15. Sandstone, thin-bedded, silty, calcareous, micaceous, very fine grained to medium-grained, light-olive-gray; thin interbedded siltstone and shale	30	0
14. Sandstone, thick-bedded, calcareous, micaceous, pyritic, fine- to coarse-grained, light-gray; contains orange (heulandite(?)) specks; contains heavy-mineral suite; angular grains	32	0
13. Sandstone, thin-bedded, silty, calcareous, very fine grained to fine-grained, light-olive-gray; thin interbedded siltstone and shale	18	0
12. Sandstone, thick-bedded, calcareous, micaceous, very fine grained to fine-grained, light-olive-gray; thin interbedded siltstone	25	0
11. Shale, massive, sandy, pyritic, light-gray; contains orange (heulandite(?)) specks and thin interbedded siltstone	27	0
10. Siltstone, thin-bedded, sandy, micaceous, medium-dark-gray; thin interbedded shale	8	0
9. Shale, massive, silty, micaceous, olive-gray	15	0
8. Sandstone, thick-bedded, calcareous, very fine grained to coarse-grained, light-gray; predominantly quartz grains; rounded to subangular grains	32	0
7. Sandstone, thin-bedded, silty, calcareous, very fine grained to fine-grained, light-gray; contains orange (heulandite(?)) specks	8	0
6. Shale, massive, sandy, pyritic, medium-gray to olive-gray with orange (heulandite(?)) specks	36	0
5. Sandstone, massive, arkosic, medium- to coarse-grained, light-olive-gray (5*Y* 6/1); interbedded silty very fine grained sandstone and carbonaceous siltstone in the lower 10 ft	28	0
4. Coal (Big Dirty coal bed—measured at caved portal of Williams mine)	17	0

	In.
Bone	1
Coal	26
Bony coal	4
Siltstone, carbonaceous, sandy	3
Siltstone, very carbonaceous	3
Coal	2
Sandstone, fine-grained, arkosic	2
Siltstone, carbonaceous	12
Coal	5
Bone	1
Coal	1
Siltstone, carbonaceous	12
Sandstone, fine-grained, arkosic	9
Siltstone, very carbonaceous	3
Coal	21

Composite section of the Eagle Sandstone, measured on west side of the Yellowstone River in the NE¼ sec. 27, T. 2 S., R. 9 E., and adjusted with section of the Deerfield Oil Corp. Strong 1 well in SW¼ sec. 11, T. 2 S., R. 9 E., Park County, Mont.—Continued

Eagle Sandstone (Upper Cretaceous)—Continued	Ft	In.
Sandstone, very fine grained	2	
Coal	2	
Siltstone, very carbonaceous; stringers of coal	16	
Sandstone, very fine grained, arkosic	10	
Bone	3	
Sandstone, very fine grained	2	
Siltstone, carbonaceous	4	
Coal	20	
Siltstone, carbonaceous	3	
Coal	1	
Sandstone, very fine grained	3	
Bone	4	
Bony coal	10	
Coal	4	
Siltstone, very carbonaceous	15	
Total Eagle Sandstone above Virgelle Member	496	0
Virgelle Sandstone Member:		
3. Sandstone, massive, indurated, calcareous, light-gray (*N*7), fine- to medium-grained, arkosic; weathers to grayish yellow (5*Y* 7/4)	62	0
2. Siltstone, micaceous, carbonaceous; interbedded fine- to medium-grained sandstone	27	0
1. Sandstone, massive, indurated, light-gray (*N*7), fine-grained, arkosic. Contains heavy-mineral suite. Weathers to yellowish gray (5*Y* 7/2)	28	0
Total thickness of Virgelle Sandstone Member	117	0
Total thickness of Eagle Sandstone	613	0

Telegraph Creek Formation.

COKEDALE FORMATION

Stratigraphic section 16 of the Cokedale Formation of the Livingston Group, measured at the abandoned townsite of Cokedale, Mont. (sections 1 and 2, fig. 15), is the type section of the formation.

SECTION 16

Type section of the Cokedale Formation of the Livingston Group, measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.

[Measured by A. E. Roberts and A. L. Benson, 1961]

Upper Cretaceous—Livingston Group—Miner Creek Formation.

SECTION 16—Continued

Type section of the Cokedale Formation of the Livingston Group measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Cokedale Formation:	Ft	In..
186. Siltstone, thick-bedded, tuffaceous, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	3	4
185. Sandstone, volcanic, thin- to medium-bedded, fine-grained, andesitic, calcareous, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	2	2
184. Covered interval—probably siltstone, light-olive-gray	20	6
183. Sandstone, volcanic, massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, light-olive-gray (5*Y* 5/2); weathers to pale yellowish brown (10*YR* 6/2); ridge former	7	5
182. Siltstone, thick-bedded, tuffaceous, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2)	5	9
181. Sandstone, volcanic, massive, crossbedded, fine- to medium-grained, andesitic, indurated, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1); ridge former	7	8
180. Siltstone, medium-bedded, tuffaceous, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2)	2	9
179. Sandstone, volcanic, massive, very fine grained, silty, andesitic, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	8	0
178. Sandstone, volcanic, thin-bedded, crossbedded, fine-grained, andesitic; indurated, light-olive-gray (5*Y* 5/2); has banded character imparted by thin (less than ⅛ in.) layers of ferromagnesian minerals on bedding planes; weathers to yellowish gray (5*Y* 7/2); ridge former	12	3
177. Siltstone, massive, tuffaceous, grayish-olive (10*Y* 4/2); weathers to greenish gray (5*GY* 6/1)	17	10
176. Sandstone, volcanic, massive, fine-grained, andesitic, indurated, light-olive-gray (5*Y* 5/2); has pronounced crossbedding; contains bronze-colored biotite; has banded character imparted by thin (less than 0.25 in.) layers of ferromagnesian minerals on bedding planes; weathers to yellowish gray (5*Y* 7/2); ridge former	6	6
175. Siltstone, medium-bedded, tuffaceous, olive-gray (5*Y* 3/2); weathers to yellowish gray (5*Y* 7/2)	1	5
174. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2)	1	2
173. Siltstone, thick-bedded, tuffaceous, olive-gray (5*Y* 3/2); weathers to yellowish gray (5*Y* 7/2)	2	3

SECTION 16—Continued

Type section of the Cokedale Formation of the Livingston Group, measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Cokedale Formation—Continued	Ft	In.
172. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2)	1	4
171. Covered interval—probably siltstone, olive-gray	8	2
170. Sandstone, volcanic, thin-bedded, fine-grained, andesitic light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2)		11
169. Covered interval—probably siltstone, olive-gray	20	6
168. Sandstone, volcanic, massive, fine- to medium-grained, poorly sorted, andesitic, indurated, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2); ridge former	7	10
167. Siltstone, massive, tuffaceous, olive-gray (5*Y* 3/2); weathers to yellowish gray (5*Y* 7/2); contains fresh-water gastropods; USGS Mesozoic loc. 28593	6	4
166. Sandstone, volcanic, massive, crossbedded, fine-grained, andesitic, indurated, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2); slight tendency to form ridges	4	0
165. Siltstone, massive, tuffaceous, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2); contains heulandite	142	7
164. Sandstone, volcanic, thin- to medium-bedded, fine- to medium-grained, poorly sorted, andesitic dusky-yellow-green (5*GY* 5/2); weathers to moderate yellowish brown (10*YR* 5/4); ridge former	6	3
163. Siltstone, massive, tuffaceous, olive-gray (5*Y* 3/2); weathers to yellowish gray (5*Y* 7/2); poorly exposed	11	5
162. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 6/2); weathers to pale yellowish brown (10*YR* 5/2)	3	6
161. Covered interval—probably siltstone, olive-gray	39	6
160. Sandstone, volcanic, thin- to medium-bedded, fine-grained, andesitic, light-olive-gray (5*Y* 5/2), weathers to pale yellowish brown (10*YR* 6/2); top bed of of prominent ridge-forming sandstone unit	7	4
159. Sandstone, volcanic, thin-bedded, fine-grained, silty, clayey, andesitic, dark-greenish-gray (5*G* 4/1); contains red specks of heulandite; weathers to yellowish gray (5*Y* 7/2)	16	5
158. Sandstone, volcanic, thin- to thick-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); contains some clay lenses or layers, generally less than 3 in. thick; weathers to light olive gray (5*Y* 5/2); ridge former	10	3

SECTION 16—Continued

Type section of the Cokedale Formation of the Livingston Group, measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Cokedale Formation—Continued	Ft	In.
157. Siltstone, medium-bedded, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	1	3
156. Sandstone, volcanic, conglomeratic, massive, fine- to coarse-grained, very poorly sorted, andesitic, light-olive-gray (5*Y* 5/2); contains pebbles of volcanic rock and mudstone; weathers to pale yellowish brown (10*YR* 6/2); ridge former	4	8
155. Siltstone, thick-bedded, olive-gray (5*Y* 3/2); weathers to light olive-gray (5*Y* 5/2)	2	0
154. Sandstone, volcanic, conglomeratic, thick-bedded, fine- to coarse-grained, very poorly sorted, andesitic, light-olive-gray (5*Y* 5/2); pebbles are small (as much as 1 in. in longest dimension but generally less than 0.25 in.), composed of volcanic rock and mudstone and not abundant; weathers to pale yellowish brown (10*YR* 6/2); ridge former	3	8
153. Siltstone, medium-bedded, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	1	1
152. Sandstone, volcanic, massive, fine- to very fine grained, silty, andesitic, indurated, light-olive-gray (5*Y* 5/2); weathers to light olive gray (5*Y* 6/1); contains macerated plant fragments	4	9
151. Siltstone, thick-bedded, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	3	11
150. Sandstone, volcanic, thick-bedded, fine-grained, andesitic, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2); very slight ridge former	2	6
149. Siltstone, massive, tuffaceous, clayey, poorly sorted, olive-gray (5*Y* 4/1); contains some fine sand grains and granules and pebbles of mudstone; weathers to yellowish gray (5*Y* 7/2)	22	9
148. Siltstone, massive tuffaceous, clayey, light-olive-gray (5*Y* 5/2); contains some very fine sand grains; weathers to dusky yellow (5*Y* 6/4)	23	3
147. Sandstone, volcanic, thin- to medium-bedded, fine-grained, andesitic, indurated, light-olive-gray (5*Y* 5/2); weathers to pale yellowish brown (10*YR* 6/2); top of prominent ridge-forming sandstone unit	5	0
146. Sandstone, volcanic, thick-bedded, very fine grained, silty, andesitic, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	3	2
145. Sandstone, volcanic, medium-bedded, crossbedded, fine-grained, andesitic, light-olive-gray (5*Y* 6/1); has banded character imparted by thin (less than 1/16 in.) layers of ferromagnesian minerals on		

SECTION 16—Continued

Type section of the Cokedale Formation of the Livingston Group, measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Cokedale Formation—Continued	Ft	In.
bedding planes; weathers to pale yellowish brown (10*YR* 6/2)	1	10
144. Sandstone, volcanic, massive, very fine grained, silty, andesitic, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	21	5
143. Sandstone, volcanic, medium- to thick-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to pale yellowish brown (10*YR* 6/2); ridge former	4	3
142. Siltstone, massive, tuffaceous, olive-green (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2)	8	0
141. Sandstone, volcanic, medium-bedded to massive, crossbedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to pale, yellowish brown (10 *YR* 6/2); very prominent ridge former	13	8
140. Siltstone, volcanic, medium-bedded to massive, crossbedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to pale yellowish brown (10*YR* 6/2); very prominent ridge former	6	7
139. Sandstone, volcanic, thick-bedded, fine-grained, andesitic, indurated, medium-light-gray (*N*6); has banded character imparted by thin (less than 1/16 in.) layers of ferromagnesian minerals on bedding planes; weathers to light olive gray (5*Y* 6/1); slight ridge former	2	6
138. Siltstone, massive, tuffaceous, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	18	0
137. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, slightly indurated, medium-light-gray (*N*6); has banded character imparted by thin (less than 1/16 in.) layers of ferromagnesian minerals on bedding planes; weathers to light olive gray (5*Y* 6/1)	1	4
136. Siltstone, massive, tuffaceous, clayey, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	18	6
135. Sandstone, volcanic, medium- to thick-bedded, fine-grained, andesitic, slightly indurated in the lower half, greenish-gray (5*GY* 6/1); weathers to yellowish gray (5*Y* 7/2) and light olive gray (5*Y* 6/1); contains a few plant fragments	4	2
134. Siltstone, massive, tuffaceous, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	4	0
133. Sandstone, volcanic, conglomeratic, massive, fine- to coarse-grained, clayey, poorly sorted, andesitic, olive-gray (5*Y* 4/1); weathers to dark yellowish brown (10*YR* 4/2); pebbles and cobbles are andesite; slight tendency to form ridges	4	6
132. Siltstone, massive, tuffaceous, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); a 2-ft-thick zone in the middle of the unit and a 6-in.-thick zone 1 ft from the base of the unit are well-indurated	18	8
131. Sandstone, volcanic, medium- to thick-bedded, very fine grained, silty, andesitic, medium-gray (*N*5); weathers to pale yellowish brown (10*YR* 6/2); slight tendency to form ridges	4	0
130. Siltstone, massive, tuffaceous, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	75	10
129. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, well-indurated in lower 7 in., dusky-yellow-green (5*GY* 5/2); weathers to pale yellowish brown (10*YR* 6/2)	17	1
128. Siltstone, massive, tuffaceous, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	12	7
127. Sandstone, volcanic, thick-bedded, very fine grained, andesitic, yellowish-gray (5*Y* 7/2); weathers to light olive gray (5*Y* 6/1); slight tendency to form ridges	3	4
126. Siltstone, massive, tuffaceous, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	15	1
125. Sandstone, volcanic, massive, fine-grained, andesitic, yellowish-gray (5*Y* 7/2); weathers to light olive gray (5*Y* 6/1); prominent ridge former	8	0
124. Siltstone, massive, clayey, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	21	11
123. Sandstone, volcanic, massive, crossbedded, medium- to coarse-grained; contains some granule-size grains of mudstone on some bedding planes; poorly sorted; andesitic; dusky-yellow-green (5*GY* 5/2); weathers to dark yellowish brown (10*YR* 4/2); contains a 6-in.-thick well-indurated zone at top of unit	6	6
122. Sandstone, volcanic, thin-bedded, fine-grained, well-indurated, andesitic, olive-gray (5*Y* 4/1); weathers to brownish gray (5*YR* 4/1)		6
121. Siltstone, massive, clayey, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	10	11
120. Sandstone, volcanic, conglomeratic, thin- to medium-bedded, crossbedded, fine- to medium-grained, andesitic, olive-gray (5*Y* 4/1); pebbles are in lowest 28 in. of unit and are of volcanic rocks, quartzite, and chert; weathers to dark yellowish brown (10*YR* 4/2); ridge former	3	4

SECTION 16—Continned

Type section of the Cokedale Formation of the Livingston Group, measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Cokedale Formation—Continued	Ft	In.
119. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains a 4-ft.-thick lens of fine-grained sandstone 1 ft from base	27	8
118. Sandstone, volcanic, thin- to thick-bedded, crossbedded, fine-grained, andesitic, dark-greenish-gray (5*GY* 4/1); weathers to dark yellowish brown; ridge former	4	6
117. Siltstone, massive, light-olive-gray (5*Y* 5/2); weathers to dusky yellow (5*Y* 6/4); poorly exposed	11	10
116. Sandstone, volcanic, medium-bedded, very fine to fine-grained, andesitic, well-indurated, medium-gray (*N*5); weathers to pale yellowish brown (10*YR* 6/2)	1	3
115. Sandstone, volcanic, thin- to thick-bedded, crossbedded, fine-grained, andesitic, poorly indurated, medium-gray (*N*5); weathers to pale yellowish brown (10 *YR* 6/2)	3	1
114. Sandstone, volcanic, thin- to thick-bedded, crossbedded, fine-grained, andesitic, medium-gray (*N*5); contains a few scour-and-fill deposits that bear mudstone pebbles as much as 1 in. in longest dimension; weathers to pale yellowish brown (10*YR* 6/2); slight tendency to form ridges	2	0
113. Siltstone, massive, clayey, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	12	7
112. Sandstone, volcanic, thin- to thick-bedded, crossbedded, fine- to medium-grained, andesitic, medium-gray (*N*5); weathers to olive gray (5*Y* 4/1); contains petrified wood and dinosaur bones; slight ridge former	4	7
111. Siltstone, massive, tuffaceous, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	18	7
110. Bentonite, poorly exposed		6
109. Siltstone, massive, tuffaceous, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	17	10
108. Sandstone, volcanic, thin-bedded, crossbedded, medium-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); contains dinosaur bones and petrified wood; ridge former	3	0
107. Siltstone, thick-bedded, well-indurated, dark-gray (*N*3); weathers to pale brown (5*YR* 5/2); contains petrified wood and plant fragments; slight tendency to form ridges; USGS Paleobotany loc. D4120	2	2

SECTION 16—Continued

Type section of the Cokedale Formation of the Livingston Group, measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Cokedale Formation—Continued	Ft.	In.
106. Siltstone, thin-bedded, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); contains macerated plant fragments; poorly exposed	2	5
105. Sandstone, volcanic, thin- to medium-bedded, crossbedded, fine- to medium-grained, andesitic, medium-gray (*N*5); weathers to light olive gray (5*Y* 6/1)	1	3
104. Sandstone, volcanic, thin- to medium-bedded, fine-grained, clayey, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); poorly exposed	4	4
103. Sandstone, volcanic, thin- to thick-bedded, medium- to coarse-grained, very poorly sorted, andesitic, grayish-olive-green (5*GY* 3/2); contains small-scale crossbedding; weathers to light olive gray (5*Y* 6/1); slight tendency to form ridges	2	8
102. Siltstone, thin-bedded, well-indurated, dark-gray (*N*3); weathers to pale brown (5*YR* 5/2) and light olive gray (5*Y* 6/1); contains plant fragments; USGS Paleobotany loc. D1815–2		6
101. Mudstone, massive, tuffaceous, silty, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains macerated plant fragments; poorly exposed; USGS Paleobotany loc. D1815–1	9	4
100. Sandstone, volcanic, medium- to thick-bedded, fine to coarse grained, andesitic, very poorly sorted, medium-gray (*N*5), weathers to olive gray (5*Y* 4/1); locally contains crossbedded and scour-and-fill deposits 0.5–1 ft. thick; contains petrified wood and some mudstone pebbles; slight tendency to form ridges	6	8
99. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); very poorly exposed	9	6
98. Sandstone, volcanic, massive, crossbedded, medium- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to brownish black (5*YR* 2/1) or, less commonly, to moderate yellowish brown (10*YR* 5/4); contains many small channels filled with pebbles and granule-size sand composed of lithic fragments; contains petrified wood; ridge former	15	0
97. Tuff, medium-bedded, water-laid, yellow-green (5*GY* 6/2); weathers to yellowish gray (5*Y* 7/2); contains petrified wood; overlying unit has channeled into this unit	1	0
96. Covered interval—probably water-laid tuff	10	0

SECTION 16—Continued

Type section of the Cokedale Formation of the Livingston Group, measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Cokedale Formation—Continued	Ft	In.
95. Sandstone, volcanic, medium-bedded, coarse-grained, very poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to moderate yellowish brown (10*YR* 5/4); contains pebbles and granule-size sand composed of lithic fragments	2	6
94. Tuff, medium-bedded, water-laid, yellow-green (5*GY* 6/2); weathers to yellowish gray (5*Y* 7/2)	2	0
93. Sandstone, volcanic, massive, crossbedded in part, coarse-grained, very poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers slightly to moderate yellowish brown (10*YR* 5/4;) pebbles and granule-size sand composed of lithic fragments are rare to common; contains petrified wood; ridge former	5	0
92. Sandstone, volcanic, conglomeratic, thick-bedded, crossbedded, very coarse grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4); contains petrified wood	2	0
91. Tuff, medium-bedded, well-indurated, water-laid, olive-gray (5*Y* 4/1); weathers to moderate yellowish brown (10*YR* 5/4); contains plant fragments	1	0
90. Sandstone, volcanic, massive, fine- to coarse-grained, very poorly sorted, andesitic, grayish-olive (10*Y* 4/2); pebbles and granules composed of lithic fragments are rare to plentiful: weathers to pale olive (10*Y* 6/2); recovered large fragments of leg bones from the dinosaur, ***Monoclonius***, from this unit; poorly exposed	70	0
89. Sandstone, medium-bedded, very fine grained, well-indurated, fairly well sorted, pale-grayish-green (10*G* 5/2); weathers to moderate yellowish brown (10*YR* 5/4); unit is transitional between underlying quartzose sands and overlying volcanic sands	1	0
88. Covered interval—probably tuffaceous, fine-grained sandstone similar to overlying unit, except nonindurated	7	0
87. Sandstone, quartzose, massive to thin-bedded, fine-grained, fairly well sorted, well-indurated, light-olive-gray (5*Y* 6/1); weathers to yellowish gray (5*Y* 7/2); contains heavy-mineral suite; ridge former; units 87, 88, and 89 probably western equivalent to part of Parkman Sandstone	8	0
86. Covered interval—probably tuffaceous siltstone, light-olive-gray (5*Y* 5/2)	80	0
85. Sandstone, volcanic, thin- to medium-bedded, very fine grained, andesitic, well-indurated, calcareous, dark-greenish-gray (5*GY*4/1); weathers to pale brown (5*YR*5/2)	6	0

SECTION 16—Continued

Type section of the Cokedale Formation of the Livingston Group, measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Cokedale Formation—Continued	Ft	In.
84. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); tuffaceous throughout; contains macerated plant fragments; USGS Paleobotany loc. D1611	76	0
83. Sandstone, volcanic, thin- to medium-bedded, very fine grained, andesitic, well-indurated, calcareous, dark-greenish-gray (5*GY* 4/1); weathers to pale brown (5*YR* 5/2)	3	3
82. Sandstone, quartzose, thin-bedded to massive, crossbedded, fine-grained, fairly well sorted, resembles quartzose beds in the Eagle Sandstone; medium-light-gray (*N*6); weathers to yellowish gray (5*Y* 7/2) and white; contains heavy-mineral suite	7	7
81. Tuff, bentonitic, pale-greenish-yellow (10*Y* 8/2); weathers to yellowish gray (5*Y* 8/1)	3	5
80. Sandstone, volcanic, thin- to medium-bedded, very fine grained, andesitic, well-indurated, calcareous, dark-greenish-gray (5*GY* 4/1); weathers to pale brown (5*YR* 5/2)	3	5
79. Claystone, thick-bedded, dark-greenish-gray (5*GY* 4/1); weathers to greenish gray (5*GY* 6/1)	3	3
78. Sandstone, volcanic, thin- to medium-bedded, very fine grained, andesitic, well-indurated, calcareous, dark-greenish-gray (5*GY* 4/1); weathers to pale brown (5*YR* 5/2)	1	1
77. Claystone, massive, dark-greenish-gray (5*GY* 4/1); weathers to greenish gray (5*GY* 6/1)	9	6
76. Sandstone, volcanic, medium-bedded, very fine grained, andesitic, well-indurated, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains macerated plant fragments; USGS Paleobotany loc. D1610	1	2
75. Siltstone, massive, sandy, tuffaceous, clayey, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2)	19	6
74. Tuff, massive, bentonitic, pale-greenish-yellow (10*Y* 8/2); weathers to yellowish gray (5*Y* 8/1)	19	0
73. Sandstone, volcanic, massive, very fine grained, andesitic, tuffaceous, silty, clayey, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2)	7	10
72. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); carbonaceous in the upper part	24	0
71. Sandstone, volcanic, thin- to thick-bedded, fine-grained, andesitic, well-indurated, medium-gray (*N*5); weathers to light-olive gray (5*Y* 6/1); contains petrified wood	2	8

SECTION 16—Continued

Type section of the Cokedale Formation of the Livingston Group, measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Cokedale Formation—Continued	*Ft*	*In.*
70. Siltstone, massive, very carbonaceous, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	9	2
69. Sandstone, volcanic, thin- to thick-bedded, fine to coarse-grained, andesitic, well-indurated, grayish-olive-green (5*GY* 3/2); weathers to light olive gray (5*Y* 5/2); locally contains scour-and-fill channels that bear granules to small (as much as 1 in. in diameter) pebbles of volcanic rock and mudstone; contains thin beds of interbedded siltstone; contains petrified wood and plant fragments; ridge former	19	5
68. Siltstone, thick-bedded, sanay, tuffaceous, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2)	4	11
67. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, well-indurated, medium-gray (*N*4); weathers to light olive gray (5*Y* 5/2); contains petrified wood	1	1
66. Siltstone, thick-bedded, sandy, medium-dark-gray (*N*4); weathers to light olive gray (5*Y* 6/1)	2	5
65. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, well-indurated, medium-gray (*N*4); weathers to light olive gray (5*Y* 5/2); contains petrified wood	1	6
64. Siltstone, massive, sandy, medium-dark-gray (*N*4); weathers to light olive gray (5*Y* 6/1); locally slightly calcareous; contains abundant petrified wood—mostly palm trees—and some macerated plant fragments	8	4
63. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, well-indurated, medium-gray (*N*4); weathers to light olive gray (5*Y* 5/2); contains petrified wood	3	9
62. Siltstone, medium-bedded, sandy, medium-dark-gray (*N*4); weathers to light olive gray (5*Y* 6/1)	1	10
61. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, well-indurated, medium-gray (*N*4); weathers to light olive gray (5*Y* 5/2); contains petrified wood	5	5
60. Siltstone, thick-bedded, sandy, medium-dark-gray (*N*4); weathers to light olive gray (5*Y* 6/1)	2	1
59. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, well-indurated, medium-gray (*N*4); weathers to light olive gray (5*Y* 5/2); contains petrified wood		11
58. Sandstone, volcanic, thick-bedded, very fine grained, andesitic, silty, clayey, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); contains macerated plant fragments	2	11

SECTION 16—Continued

Type section of the Cokedale Formation of the Livingston Group, measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Cokedale Formation—Continued	*Ft*	*In.*
57. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, well-indurated, locally calcareous, light-olive-gray (5*Y* 5/2); weathers to light olive gray (5*Y* 6/1); contains plant fragments and leaf prints	5	9
56. Claystone, massive, very carbonaceous, dark-gray (*N*3); weathers to light olive gray (5*Y* 6/1); contains macerated plant fragments	5	2
55. Sandstone, volcanic, medium- to thick-bedded, crossbedded, fine- to coarse-grained and locally conglomeratic with pebbles of volcanic rock and mudstone as much as 0.75 in. in diameter, very poorly sorted, andesitic, medium-gray (*N*5); weathers to light gray (*N*7); grains angular to subangular; contains abundant feldspar and biotite; slightly calcareous; contains wood and plant fragments; ridge former	38	8
54. Claystone, thick-bedded, very carbonaceous, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	3	5
53. Tuff, devitrified, greenish-gray (5*GY* 6/1); weathers to yellowish gray (5*Y* 7/2) to white; contains euhedral crystals of biotite and feldspar	3	1
52. Mudstone, massive, sandy, olive-gray (5*Y* 5/4); weathers to light olive gray (5*Y* 6/1); contains abundant macerated plant fragments	4	10
51. Siltstone, massive, clayey, olive-gray (5*Y* 4/1); contains rare red specks of heulandite; weathers to light olive gray (5*Y* 6/1)	5	4
50. Siltstone, thin- to medium-bedded, well-indurated, grayish-olive-green (5*GY* 3/2); weathers to grayish brown (5*YR* 3/2)	1	8
49. Sandstone, volcanic, thin-bedded to massive, fine- to coarse-grained but dominantly fine-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish olive (10*Y* 4/2); locally contains scour-and-fill channels that bear granule-size grains; contains abundant petrified wood; ridge former	13	4
48. Sandstone, volcanic, conglomeratic, thin- to medium-bedded, crossbedded, fine- to coarse-grained, very poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); pebbles, from granule size to 1 in. in diameter, are composed of volcanic rock and mudstone; contains lenses of clay—grayish-olive-green (5*GY* 3/2); contains abundant fossil wood, dominantly of palm trees, and plant fragments; grades into overlying sandstone	4	10

SECTION 16—Continued

Type section of the Cokedale Formation of the Livingston Group, measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Cokedale Formation—Continued	Ft	In.
47. Sandstone, thin-bedded to massive, fine- to coarse-grained, feldspathic (dominantly plagioclase), medium-light-gray (*N*6); grains angular to subangular; locally contains calcareous lenses and stringers; weathers to yellowish gray (5*Y* 7/2); massive spheroidal weathering	6	7
46. Claystone, thin-bedded, very carbonaceous, grayish-black (*N*2); weathers to medium gray (*N*5); contains macerated plant fragments	1	3
45. Sandstone, volcanic, thin-bedded, fine- to medium-grained, tuffaceous, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4); contains macerated plant fragments	1	6
44. Claystone, thin-bedded, very carbonaceous, grayish-black (*N*2); weathers to medium gray. (*N*5); contains macerated plant fragments		7
43. Sandstone, volcanic, thin-bedded, fine-grained, tuffaceous, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4)		11
42. Claystone, thin-bedded, very carbonaceous, grayish-black (*N*2); weathers to medium gray (*N*5); contains macerated plant fragments	4	6
41. Mudstone, thin-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	2	8
40. Bentonite, sandy, devitrified	1	7
39. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	13	0
38. Sandstone, volcanic, thin-bedded, very fine grained, silty, bentonitic, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4)		4
37. Claystone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	1	11
36. Sandstone, volcanic, thin-bedded, very fine grained, silty, bentonitic, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4)	2	9
35. Claystone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	1	8
34. Sandstone, volcanic, thin-bedded, fine-grained, bentonitic, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4)		4
33. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	16	10
32. Sandstone, volcanic, thin-bedded to massive, fine- to medium-grained, poorly sorted, andesitic, carbonaceous, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4); contains macerated plant fragments	5	4
31. Coal, bony, dull, soft		3

SECTION 16—Continued

Type section of the Cokedale Formation of the Livingston Group, measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Cokedale Formation—Continued	Ft	In.
30. Coal, blocky, bright, brown when cut, hard		4
29. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4); very micaceous		2
28. Shale, very carbonaceous, brownish-black (5*YR* 2/1); weathers to brownish gray (5*YR* 4/1)	1	9
27. Coal, blocky, bright, brown when cut, hard		10
26. Siltstone, thin-bedded, tuffaceous, clayey, carbonaceous, brownish-black (5*YR* 2/1); weathers to light brownish gray (5*YR* 6/1)		4
25. Coal, bony, flaky, dull; contains a few bright streaks		5
24. Shale, very carbonaceous, brownish-black (5*YR* 2/1); weathers to brownish gray (5*YR* 4/1)		4
23. Coal, bony, flaky, dull; contains a few bright streaks		3
22. Sandstone, thin-bedded, very fine grained, silty, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4)		3
21. Coal, bony, flaky, dull; contains a few bright streaks		1
20. Shale, very carbonaceous, brownish-black (5*YR* 2/1); weathers to brownish gray (5*YR* 4/1)		1
19. Sandstone, thin-bedded, very fine grained, silty, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4)		2
18. Shale, very carbonaceous, brownish-black (5*YR* 2/1); weathers to brownish gray (5*YR* 4/1)		8
17. Sandstone, thin-bedded, very fine grained, silty, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4)		1
16. Coal, bony, flaky, dull; contains a few thin bright streaks		2
15. Sandstone, thin-bedded, very fine grained, silty, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4)		1
14. Siltstone, thin-bedded, very carbonaceous, brownish-black (5*YR* 2/1); weathers to light brownish gray (5*YR* 6/1)		3
13. Coal, bony, flaky, dull; contains a few thin (generally less than ⅛ in.) bright streaks		2
12. Siltstone, thin-bedded, very carbonaceous, brownish-black (5*YR* 2/1); weathers to light brownish gray (5*YR* 6/1)		2
11. Sandstone, thin-bedded, very fine grained, silty, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4)		5
10. Siltstone, thin-bedded, very carbonaceous, brownish-black (5*YR* 2/1); weathers to light brownish gray (5*YR* 6/1)		10

SECTION 16—Continued

Type section of the Cokedale Formation of the Livingston Group, measured in the S½ sec. 23 and the NE¼ sec. 26, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Cokedale Formation—Continued	Ft	In.
9. Sandstone, thin-bedded, very fine grained, silty, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4)		8
8. Sandstone, volcanic, massive to thin-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4); locally calcareous, containing many large (2–3 ft in diameter) calcareous spheroidal concretions; contains macerated plant fragments	12	6
7. Bentonite, silty		3
6. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4); contains streaks of coal and plant fragments		11
5. Siltstone, medium-bedded, well-indurated, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2); contains macerated plant fragments		10
4. Claystone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	1	3
3. Siltstone, thick-bedded, well-indurated, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	2	10
2. Claystone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	1	9
1. Mudstone, thin-bedded, very carbonaceous, bentonitic, grayish-brown (5*YR* 3/2); weathers to pale yellowish brown (10*YR* 6/2)	1	1
Total thickness of Cokedale Formation	1, 550	0

Upper Cretaceous—Eagle Sandstone.

MINER CREEK FORMATION

Stratigraphic section 17 of the Miner Creek Formation of the Livingston Group, measured near the abandoned townsite of Cokedale, Mont. (sections 3 and 4, fig. 15), is the type section of the formation.

SECTION 17

Type section of the Miner Creek Formation of the Livingston Group, measured in the NW¼ sec. 20 and E½ sec. 19, T. 2 S., R. 9 E., Park County, Mont.

[Measured by A. E. Roberts and A. L. Benson, 1961]

Upper Cretaceous—Livingston Group—Billman Creek Formation.

Upper Cretaceous—Livingston Group—Miner Creek Formation:	Ft	In.
155. Sandstone, volcanic, thin-bedded to massive, fine-grained, andesitic, dark-greenish-gray (5*GY* 4/1); weathers to greenish gray (5*GY* 6/1); contains a few calcareous concretions as much as 8 in. in diameter; prominent ridge former	9	0

SECTION 17—Continued

Type section of the Miner Creek Formation of the Livingston Group, measured in the NW¼ sec. 20 and E½ sec. 19, T. 2 S., R. 9 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Miner Creek Formation—Continued	Ft	In.
154. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); USGS Paleobotany loc. D1613	21	1
153. Sandstone, volcanic, medium-bedded to massive, fine-grained, andesitic, grayish-green (10*GY* 5/2); weathers to light olive gray (5*Y* 6/1)	8	2
152. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	146	6
151. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, medium-light-gray (*N*6); weathers to light olive gray (5*Y* 6/1)	2	2
150. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	145	11
149. Sandstone, volcanic, thin- to medium-bedded, fine-grained, andesitic, medium-light-gray (*N*6); weathers to yellowish gray (5*Y* 7/2)	1	8
148. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	14	11
147. Sandstone, volcanic, medium-bedded, fine-grained, silty, andesitic, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)		8
146. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	3	4
145. Sandstone, volcanic, medium-bedded, fine-grained, silty, andesitic, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)		9
144. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	26	5
143. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, medium-light-gray (*N*6); weathers to light gray (*N*7)	2	0
142. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	11	10
141. Sandstone, volcanic, medium-bedded, cross-bedded, fine-grained, andesitic, light-gray (*N*7); has banded character imparted by thin (less than 1/16 in.) layers of ferromagnesian minerals on bedding planes; weathers to yellowish gray (5*Y* 8/1)	1	11
140. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	39	3
139. Sandstone, volcanic, massive, fine-grained, andesitic, medium-light-gray (*N*6); weathers to light gray (*N*7)	4	2
138. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	6	4
137. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, medium-light gray (*N*6); weathers to light gray (*N*7)		11
136. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	16	1

SECTION 17—Continued

Type section of the Miner Creek Formation of the Livingston Group, measured in the NW¼ sec. 20 and E½ sec. 19, T. 2 S., R. 9 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Miner Creek Formation—Continued	Ft	In.
135. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, medium-light-gray (*N*6); weathers to light gray (*N*7)	2	0
134. Siltstone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	2	8
133. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1)	2	8
132. Siltstone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	1	8
131. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1)	2	4
130. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	7	1
129. Sandstone, volcanic, thick-bedded, fine grained, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1)	3	8
128. Siltstone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	1	9
127. Sandstone, volcanic, thin-bedded to massive, fine-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1); prominent ridge former	12	0
126. Siltstone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	1	2
125. Sandstone, volcanic, thin- to thick-bedded, fine-grained, andesitic, grayish-green (5*G* 5/2); weathers to yellowish gray (5*Y* 7/2)	3	9
124. Siltstone, massive, tuffaceous, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	27	0
123. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to medium-grained, andesitic, grayish-green (5*G* 5/2); weathers to yellowish gray (5*Y* 7/2); prominent ridge former	9	0
122. Covered interval—probably siltstone, olive-gray	5	10
121. Sandstone, volcanic, massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, medium-light-gray (*N*6); weathers to yellowish gray (5*Y* 8/1) and white	4	6
120. Covered interval—probably siltstone, olive-gray	39	11
119. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to medium-grained, andesitic, well-indurated, medium-light-gray (*N*6); weathers to light olive gray (5*Y* 6/1); contains dinosaur bone fragments; ridge former	6	3
118. Covered interval—probably siltstone, olive-gray	95	5
117. Sandstone, volcanic, thick-bedded, fine-grained, andesitic, grayish-green (5*G* 5/2); weathers to olive gray (5*Y* 4/1)	3	6
116. Covered interval—probably siltstone, olive-gray	23	3
115. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, grayish-green (5*G* 5/2); weathers to olive gray (5*Y* 4/1)	1	4
114. Siltstone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	1	8
113. Sandstone, volcanic, medium- to thick-bedded, fine-grained, andesitic, grayish-green (5*G* 5/2); weathers to olive gray (5*Y* 4/1)	3	8
112. Siltstone, thick-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	3	8
111. Sandstone, volcanic, thick-bedded, fine- to coarse-grained, poorly sorted, andesitic, grayish-green (5*G* 5/2); weathers to olive gray (5*Y* 4/1)	5	2
110. Covered interval—probably siltstone, olive-gray	35	5
109. Sandstone, volcanic, thin-bedded, very fine grained, andesitic, greenish-gray (5*GY* 6/1); weathers to yellowish gray (5*Y* 7/2); contains abundant bronze-colored biotite	1	2
108. Siltstone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1) contains wood and plant fragments	5	2
107. Sandstone, volcanic, medium-bedded, fine- to medium-grained, poorly sorted, andesitic, medium-light-gray (*N*6); weathers to light gray (*N*7)	1	4
106. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	32	8
105. Sandstone, volcanic, massive, fine-grained, andesitic, well-indurated, grayish-green (10*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); ridge former	12	8
104. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	11	2
103. Sandstone, volcanic, medium- to thick-bedded, crossbedded, fine-grained, silty, andesitic; contains many mudstone balls—generally along bedding planes; grayish-green (5*G* 5/2); weathers to grayish yellow green (5*GY* 7/2)	4	0
102. Siltstone, thick-bedded, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	3	0
101. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to pale yellowish brown (10*YR* 6/2)	1	1

SECTION 17—Continued

Type section of the Miner Creek Formation of the Livingston Group, measured in the NW¼ sec. 20 and E½ sec. 19, T. 2 S., R. 9 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Miner Creek Formation—Continued	Ft	In.
100. Siltstone, medium-bedded, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	1	3
99. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, dusky-yellow-green (5GY 5/2); weathers to pale yellowish brown (10*YR* 6/2)		4
98. Siltstone, medium-bedded, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	1	2
97. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to pale yellowish brown (10*YR* 6/2)		4
96. Siltstone, massive, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	20	6
95. Sandstone, volcanic, thick-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to pale yellowish brown (10*YR* 6/2)	2	6
94. Siltstone, massive, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	11	0
93. Sandstone, volcanic, massive to thin-bedded, fine-grained, andesitic, well-indurated, dusky-yellow-green (5GY 5/2); weathers to pale yellowish brown (10*YR* 6/2); ridge former	8	8
92. Siltstone, thin-bedded, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)		4
91. Sandstone, volcanic, thin-bedded, fine-grained, silty, andesitic, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2)		3
90. Siltstone, thin-bedded, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)		5
89. Sandstone, volcanic, thin-bedded, fine grained, silty, andesitic, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2)		3
88. Siltstone, thin-bedded, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)		4
87. Sandstone, volcanic, thin-bedded, fine-grained, silty, andesitic, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5Y 7/2)		3
86. Siltstone, massive, dusky-yellow-green (5*GY* 5/2); contains red specks of heulandite; weathers to grayish yellow green (5*GY* 7/2)	11	0
85. Sandstone, volcanic, thick-bedded, fine-grained, silty, andesitic, well-indurated, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2); contains macerated plant fragments; ridge former	2	9

SECTION 17—Continued

Type section of the Miner Creek Formation of the Livingston Group, measured in the NW¼ sec. 20 and E½ sec. 19, T. 2 S., R. 9 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Miner Creek Formation—Continued	Ft	In.
84. Siltstone, massive, dusky-yellow-green (5*GY* 5/2); red specks of heulandite common; contains some fine sand; weathers to grayish yellow green (5*GY* 7/2)	15	11
83. Sandstone, volcanic, thin- to thick-bedded, fine-grained, andesitic, well-indurated, grayish-olive-green (5*GY* 3/2); abundant bronze-colored biotite and hornblende; weathers to greenish gray (5*GY* 6/1)	12	4
82. Sandstone, volcanic, medium-bedded to massive, fine- to medium-grained, andesitic, well-indurated, greenish-gray (5*GY* 6/1); fills channels as much as 3.5 ft deep in underlying siltstone; abundant bronze-colored biotite; weathers to moderate brown (5*YR* 4/4)	7	9
81. Siltstone, thick-bedded, grayish-olive (10*Y* 4/2); weathers to pale olive (10*Y* 6/2)	3	4
80. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, medium-light-gray (*N*6); weathers to light gray (*N*7)	2	0
79. Siltstone, medium-bedded, grayish-olive (10*Y* 4/2); weathers to pale olive (10*Y* 6/2)		6
78. Sandstone, volcanic, medium- to thick-bedded, fine-grained, andesitic, medium-light-gray (*N*6); weathers to light gray (*N*7)	3	10
77. Siltstone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains macerated plant fragments; USGS Paleobotany loc. D1612	1	9
76. Sandstone, volcanic, medium-bedded, fine-grained, andesitic; contains red specks of heulandite		6
75. Siltstone, thick-bedded, grayish-olive-green (5*GY* 3/2); weathers to grayish yellow green (5*GY* 7/2)	2	8
74. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, medium-light-gray (*N*6); contains red specks of heulandite; weathers to light gray (*N*7)		9
73. Siltstone, massive, grayish-olive-green, (5*GY* 3/2); weathers to grayish yellow green (5*GY* 7/2)	6	10
72. Sandstone, volcanic, medium-bedded, fine- to medium-grained, andesitic, medium-light-gray (*N*6); contains red specks of heulandite; weathers to light gray (*N*7)	1	0
71. Siltstone, thick-bedded, grayish-olive-green (5*GY* 3/2); weathers to grayish yellow green (5*GY* 7/2)	2	8
70. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, medium-light-gray (*N*6); contains red specks of heulandite; weathers to light gray (*N*7)		9
69. Siltstone, medium-bedded, grayish-olive-green (5*GY* 3/2); weathers to grayish yellow green (5*GY* 7/2)		9

SECTION 17—Continued

Type section of the Miner Creek Formation of the Livingston Group, measured in the NW¼ sec. 20 and E½ sec. 19, T. 2 S., R. 9 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Miner Creek Formation—Continued	*Ft*	*In.*
68. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, medium-light-gray (*N*6); contains red specks of heulandite; weathers to light gray (*N*7)		7
67. Siltstone, thick-bedded, grayish-olive-green (5*GY* 3/2); weathers to grayish yellow green (5*GY* 7/2)	3	0
66. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, medium-light-gray (*N*6); contains bronze-colored biotite; weathers to light gray (*N*7); contains macerated plant fragments		6
65. Siltstone, massive, tuffaceous, grayish-olive-green (5*GY* 3/2); contains red specks of heulandite; weathers to grayish yellow green (5*GY* 7/2)	10	6
64. Sandstone, volcanic, medium-bedded, very fine grained, silty, andesitic, greenish-gray (5*GY* 6/1); weathers to light greenish gray (5*GY* 8/1)	1	4
63. Siltstone, massive, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	21	10
62. Sandstone, volcanic medium-bedded, very fine grained, silty, andesitic, dark-yellowish-brown (10*YR* 4/2); weathers to pale yellowish brown (10*YR* 6/2); contains macerated plant fragments	1	0
61. Siltstone, thick-bedded, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	2	10
60. Bentonite		10
59. Siltstone, thick-bedded, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	3	4
58. Sandstone, volcanic, thick-bedded, fine-grained, silty, andesitic, dark-greenish-gray (5*GY* 4/1); weathers to yellowish gray (5*Y* 8/1)	2	0
57. Siltstone, massive tuffaceous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	27	3
56. Sandstone, volcanic, massive, fine- to coarse-grained, poorly sorted, andesitic, medium-light-gray (*N*6); contains granules to small pebbles composed of volcanic rock at base; weathers to light gray (*N*7)	5	9
55. Siltstone, thick-bedded, dusky-yellow-green (5*GY* 5/2); contains vienlets and red specks of heulandite; weathers to grayish yellow green (5*GY* 7/2)	2	4
54. Sandstone, volcanic, medium-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, medium-light-gray (*N*6); contains granules and small pebbles composed of volcanic rocks; weathers to light gray (*N*7), with limonitic staining	4	0
53. Siltstone, massive, tuffaceous, olive-gray (5*Y* 3/2); weathers to yellowish gray (5*Y* 7/2)	10	9
52. Bentonite	1	10
51. Siltstone, massive, tuffaceous, olive-gray (5*Y* 3/2); contains silica-cemented concretions—generally 3–6 in. in diameter; lower 2 ft grades downward into a very fine grained silty sandstone; weathers to yellowish gray (5*Y* 7/2)	48	2
50. Sandstone, volcanic, medium-bedded to massive, fine- to coarse-grained, poorly sorted, andesitic, dark-greenish-gray (5*GY* 4/1); contains mudstone pebbles; weathers to moderate brown (5*YR* 4/4)	4	2
49. Siltstone, massive, dark-yellowish-brown (10*YR* 4/2); weathers to pale yellowish brown (10*YR* 6/2); contains macerated plant fragments	21	4
48. Siltstone, medium-bedded, tuffaceous, well-indurated, medium-dark-gray (*N*4); contains bronze-colored biotite; weathers to moderate brown (5*YR* 4/4)		8
47. Tuff, silicified, well-indurated, light-greenish-gray (5*GY* 8/1); contains bronze-colored biotite; this unit might have originally been dark gray and then leached; weathers to yellowish gray (5*Y* 7/2)	3	6
46. Siltstone, massive, olive-gray (5*Y* 3/2); weathers to yellowish gray (5*Y* 7/2); poorly exposed	18	1
45. Sandstone, volcanic, medium-bedded, fine- to coarse-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	4	2
44. Siltstone, massive, olive-gray (5*Y* 3/2); weathers to yellowish gray (5*Y* 7/2); poorly exposed	23	11
Total Miner Creek Formation that lies above the Sulphur Flats Sandstone Member	1, 190	0
Sulphur Flats Sandstone Member:		
43. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, well-indurated, andesitic, light-brownish-gray (5*YR* 6/1) to grayish-green (5*G* 5/2); contains bronze-colored biotite; weathers to light olive gray (5*Y* 5/2); ridge former	10	4
42. Siltstone, medium-bedded, olive-gray (5*Y* 4/1); weathers to pale olive (10*Y* 6/2)	1	0
41. Tuff, medium-bedded, grayish-green (5*G* 5/2) and light-brownish-gray (5*YR* 6/1); weathers to light olive gray (5*Y* 6/1)	1	0
40. Sandstone, volcanic, thick-bedded, fine-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to olive gray (5*Y* 4/1)	2	0

SECTION 17—Continued

Type section of the Miner Creek Formation of the Livingston Group, measured in the NW¼ sec. 20 and E½ sec. 19, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Upper Cretaceous—Livingston Group—Miner Creek Formation—Continued		
Sulphur Flats Sandstone Member—Continued		
39. Tuff, medium-bedded, grayish-green (5*G* 5/2) and light-brownish-gray (5*YR* 6/1); weathers to light olive gray (5*Y* 6/1)	1	0
38. Sandstone, volcanic, thick-bedded, fine-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to olive gray (5*Y* 4/1)	2	0
37. Sandstone, volcanic, massive, fine- to coarse-grained, poorly sorted, andesitic, grayish-green (5*G* 5/2); weathers to light olive gray (5*Y* 5/2); ridge former	13	7
36. Tuff, medium-bedded, silicified, light-olive-gray (5*Y* 5/2); weathers to moderate yellowish brown (10*YR* 5/4); contains macerated plant fragments	1	3
35. Sandstone, volcanic, thin-bedded, medium-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to olive gray (5*Y* 4/1)		6
34. Siltstone, tuffaceous, well-indurated, light-olive-gray (5*Y* 5/2) with streaks of light-brownish-gray (5*YR* 6/1); weathers to light olive gray (5*Y* 6/1); contains a few leaf imprints		10
33. Sandstone, volcanic, thin-bedded, medium-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to olive gray (5*Y* 4/1)		6
32. Tuff, thin-bedded, light-brownish-gray (5*YR* 6/1); weathers to light olive gray (5*Y* 6/1)		3
31. Sandstone, volcanic, thin-bedded, medium-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to olive gray (5*Y* 4/1)		10
30. Tuff, medium-bedded; light-brownish-gray (5*YR* 6/1); weathers to light olive gray (5*Y* 6/1); lowest 10 in. well-indurated	1	8
29. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to medium-grained, andesitic, grayish-green (5*G* 5/2); has banded character imparted by thin (less than 1/10 in.) layers of ferromagnesian minerals on bedding planes; weathers to dark yellowish brown (10*YR* 4/2); ridge former	7	3
28. Siltstone, thick-bedded, medium-light-gray (*N*6); weathers to olive gray (5*Y* 4/1)	3	0
27. Sandstone, volcanic, medium-bedded, fine- to coarse-grained, poorly sorted, andesitic grayish-green (5*G* 5/2); weathers to light olive gray (5*Y* 5/2)	1	3
26. Siltstone, medium-bedded, medium-light-gray (*N*6); weathers to olive gray (5*Y* 4/1); lowest 1 ft well-indurated	2	8
25. Sandstone, volcanic, locally conglomeratic, massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, grayish-green (5*G* 5/2); weathers to light olive gray (5*Y* 5/2); locally contains pebbles and cobbles of volcanic rock; contains fragments of dinosaur bones; ridge former	26	0
24. Siltstone, thin-bedded, greenish-gray (5*GY* 6/1); contains some clay and fine sand; weathers to pale olive (10*Y* 6/2)		5
23. Sandstone, volcanic, thin- to thick-bedded, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); ridge former	4	1
22. Tuff, medium-bedded, light-olive-gray (5*Y* 6/1); weathers to yellowish gray (5*Y* 7/2)	2	6
21. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to pale yellowish brown (10*YR* 6/2)	1	1
20. Tuff, medium-bedded, light-olive-gray (5*Y* 6/1); weathers to yellowish gray (5*Y* 7/2)		10
19. Sandstone, volcanic, massive, crossbedded, fine- to coarse-grained, andesitic, well-indurated, dusky-yellow-green (5*GY* 5/2); weathers to pale yellowish brown (10*YR* 6/2); ridge former	4	6
18. Siltstone, medium-bedded, tuffaceous, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	1	1
17. Siltstone, medium-bedded, tuffaceous, well-indurated, pale-yellowish-brown (10*YR* 6/2); weathers to yellowish gray (5*Y* 7/2); contains macerated plant fragments		8
16. Siltstone, medium-bedded, tuffaceous, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	1	1
15. Siltstone, medium-bedded, sandy, tuffaceous, medium-dark-gray (*N*4); weathers to moderate brown (5*YR* 4/4); contains macerated plant fragments	1	0
14. Siltstone, medium-bedded, tuffaceous, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	2	3
13. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to greenish gray (5*GY* 6/1)	1	1
12. Siltstone, medium-bedded, tuffaceous, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	2	10
11. Siltstone, medium-bedded, tuffaceous, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 5/2); contains macerated plant fragments	1	0
10. Siltstone, medium-bedded, tuffaceous, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	2	1

SECTION 17—Continued

Type section of the Miner Creek Formation of the Livingston Group, measured in the NW¼ sec. 20 and E½ sec. 19, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Upper Cretaceous—Livingston Group—Miner Creek Formation—Continued		
Sulphur Flats Sandstone Member—Continued		
9. Tuff, medium-bedded, well-indurated, light-brownish-gray (5*YR* 6/1); weathers to yellowish gray (5*Y* 7/2); slight tendency to form ridges		11
8. Siltstone, massive, tuffaceous, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	5	5
7. Sandstone, volcanic, massive, cross bedded, fine- to medium-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to pale olive (10*Y* 6/2); mudstone pebbles as much as 2 in. in diameter in lowest 1 ft of bed; slight tendency to form ridges	2	8
6. Siltstone, thick-bedded, tuffaceous, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2)	3	10
5. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, grayish-yellow-green (5*GY* 7/2); weathers to pale olive (10*Y* 6/2)	2	8
4. Siltstone, medium-bedded, tuffaceous, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2); contains petrified wood and macerated plant fragments	1	7
3. Sandstone, volcanic, massive, crossbedded, fine-grained, andesitic, grayish-yellow-green (5*GY* 7/2) weathers to pale olive (10*Y* 6/2); contains petrified wood; ridge former	8	11
2. Siltstone, massive, tuffaceous, grayish-olive-green (5*GY* 3/2); weathers to dusky yellow green (5*GY* 5/2)	24	1
1. Sandstone, quartzose, thin- to thick-bedded, fine-grained, mottled yellowish-gray (5*Y* 8/1) and yellowish-gray (5*Y* 7/2); contains calcareous lenses and stringers as much as 4 in. thick; weathers to pale yellowish brown (10*YR* 6/2); good marker bed due to its lithology and mottled light color; slight tendency to form ridges	6	6
Total thickness of Sulphur Flats Sandstone Member	160	0
Total thickness of Miner Creek Formation	1,350	0
Upper Cretaceous—Livingston Group—Cokedale Formation.		

BILLMAN CREEK FORMATION

Stratigraphic section 18 of the Billman Creek Formation of the Livingston Group, measured across the valley of Billman Creek north of the abandoned townsite of Cokedale, Mont. (sections 5–7, fig. 15), is the type section of the formation.

SECTION 18

Type section of the Billman Creek Formation of the Livingston Group, measured in the W½ sec. 18, T. 2 S., R. 9 E., and the S½ sec. 13, T. 2 S., R. 8 E., Park County, Mont.

[Measured by A. E. Roberts and A. L. Benson, 1961]

	Ft	In.
Upper Cretaceous—Livingston Group—Hoppers Formation.		
Upper Cretaceous—Livingston Group—Billman Creek Formation:		
163. Claystone, massive, olive-black (5*Y* 2/1); weathers to light olive gray (5*Y* 6/1)	1	6
162. Siltstone, thick-bedded, clayey, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	2	6
161. Claystone, massive, olive-black (5*Y* 2/1); weathers to light olive gray (5*Y* 6/1)	17	0
160. Sandstone, volcanic, thin-bedded to massive, fine-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	3	6
159. Claystone, massive, olive-black (5*Y* 2/1); weathers to light olive gray (5*Y* 6/1)	11	2
158. Sandstone, volcanic, thin-bedded to massive, fine-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	5	4
157. Claystone, massive, olive-black (5*Y* 2/1); weathers to light olive gray (5*Y* 6/1)	10	9
156. Sandstone, volcanic, thin-bedded, cross-bedded, fine-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	1	8
155. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	13	10
154. Sandstone, volcanic, thin-bedded, cross-bedded, fine-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	3	6
153. Claystone, thick-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	3	2
152. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); has banded character imparted by thin (less than ¹⁄₁₆ in.) layers of ferromagnesian minerals on bedding planes; massive spheroidal weathering; weathers to yellowish gray (5*Y* 7/2); contains plant fragments	8	4
151. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	11	4
150. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	1	8
149. Claystone, thick-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains calcareous nodules as much as 8 in. in diameter	3	0

SECTION 18—Continued

Type section of the Billman Creek Formation of the Livingston Group, measured in the W½ sec. 18, T. 2 S., R. 9 E., and the S½ sec. 13, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Billman Creek Formation—Continued	Ft	In.
148. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	1	0
147. Claystone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	1	9
146. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	2	8
145. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	16	2
144. Sandstone, volcanic, thin-bedded to massive, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); has banded character imparted by thin (less than 1/16 in.) layers of ferromagnesian minerals along bedding planes; contains calcareous nodules and stringers; weathers to yellowish gray (5*Y* 7/2); contains macerated plant fragments; ridge former	21	1
143. Claystone, massive, olive-black (5*Y* 2/1); weathers to olive gray (5*Y* 4/1)	2	8
142. Sandstone, volcanic, thin- to medium-bedded, fine-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	1	5
141. Claystone, massive, olive-black (5*Y* 2/1); weathers to olive gray (5*Y* 4/1)	10	0
140. Sandstone, volcanic, thin- to medium-bedded, fine-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	1	0
139. Claystone, thick-bedded, brownish-black (5*YR* 2/1) and brownish-gray (5*YR* 4/1); weathers to light brownish gray (5*YR* 6/1)	3	4
138. Sandstone, volcanic, thin- to medium-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	2	4
137. Siltstone, thick-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains macerated plant fragments; USGS Paleobotany loc. D4104–B	3	4
136. Claystone, medium-bedded, olive-black (5*Y* 2/1); weathers to light olive gray (5*Y* 6/1)	1	6
135. Sandstone, volcanic, thin- to thick-bedded, fine-grained, andesitic, lower 2 ft and upper 5 ft are calcareous, dusky-yellow-green (5*GY* 5/2); weathers to greenish gray (5*GY* 6/1)	10	8

SECTION 18—Continued

Type section of the Billman Creek Formation of the Livingston Group, measured in the W½ sec. 18, T. 2 S., R. 9 E., and the S½ sec. 13, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Billman Creek Formation—Continued	Ft	In.
134. Siltstone, massive, clayey, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	10	5
133. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); somewhat brecciated and cemented by gypsum		11
132. Claystone, massive, olive-black (5*Y* 2/1) and olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	10	11
131. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	3	8
130. Claystone, massive, olive-black (5*Y* 2/1); weathers to light olive gray (5*Y* 6/1)	7	3
129. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	1	2
128. Claystone, massive, olive-black (5*Y* 2/1) and olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	5	5
127. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted (pebbles of volcanic rock as much as 2 in. in diameter are rare to common), adesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	13	.
126. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed		
125. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, very poorly sorted (contains grains as large as granules), andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); ridge former	12	4
124. Sandstone, volcanic, massive, crossbedded, fine- to medium-grained, andesitic, dusky-yellow-green (5*GY* 5/2); has banded character imparted by thin (less than ⅛ in.) layers of ferromagnesian minerals on bedding planes; spheroidal weathering; weathers yellowish gray (5*Y* 7/2); ridge former	20	8
123. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	7	3
122. Sandstone, volcanic, thin-bedded, crossbedded, fine- to medium-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	1	10
121. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	12	1

SECTION 18—Continued

Type section of the Billman Creek Formation of the Livingston Group, measured in the W½ sec. 18, T. 2 S., R. 9 E., and the S½ sec. 13, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Billman Creek Formation—Continued	Ft	In.
120. Sandstone, volcanic, thin-bedded, crossbedded, fine- to medium-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	17	4
119. Siltstone, massive, dusky-yellow-green (5*GY* 5/2); weathers to pale olive (10*Y* 6/2); poorly exposed	16	6
118. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to medium-grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); slight ridge former	18	6
117. Claystone, massive, brownish-gray (5*YR* 4/1); weathers to light brownish gray (5*YR* 6/1)	2	10
116. Sandstone, volcanic, massive, crossbedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	12	0
115. Covered interval—probably mudstone, dusky-yellow-green	61	6
114. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to medium-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2)	9	0
113. Sandstone, volcanic, massive, very fine grained, silty, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2)	5	0
112. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to medium-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2); contains wood and plant fragments; ridge former	39	1
111. Covered interval—probably mudstone, dusky-yellow-green	25	2
110. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine to medium-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to a yellowish gray (5*Y* 7/2); slight ridge former	20	6
109. Mudstone, massive, grayish-brown (5*YR* 3/2); weathers to pale yellowish brown (10*YR* 6/2); poorly exposed	114	9
108. Sandstone, volcanic, thin-bedded to massive, fine- to medium-grained, poorly sorted (contains some interbedded layers composed of granules), dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2); contains macerated plant fragments	12	8
107. Covered interval—probably siltstone, brownish-gray	35	2

SECTION 18—Continued

Type section of the Billman Creek Formation of the Livingston Group, measured in the W½ sec. 18, T. 2 S., R. 9 E., and the S½ sec. 13, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Billman Creek Formation—Continued	Ft	In.
106. Sandstone, volcanic, massive, crossbedded, fine- to medium-grained (contains some mudstone pebbles in scour-and-fill deposits), andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); ridge former	18	8
105. Mudstone, massive, brownish-gray (5*YR* 4/1); lower 20 in. is siltstone that grades upward from the underlying sandstone; contains rare small (less than 10-in. diameter) calcareous concretions; upper 4 ft is silty and fossiliferous, containing freshwater mollusks and gastropods; weathers to light brownish gray (5*YR* 6/1); USGS Mesozoic loc. 28594; USGS Paleobotany loc. D4104–A	21	10
104. Sandstone, volcanic, massive, fine-grained, silty, andesitic, olive-gray (5*Y* 3/2); contains calcareous concretions as much as 9 in. in diameter; weathers to light olive gray (5*Y* 5/2); gradational contacts with units above and below	5	8
103. Mudstone, massive, brownish-gray (5*YR* 4/1); weathers to light brownish gray (5*YR* 6/1); contains rare small (less than 6-in. diameter) calcareous concretions	16	1
102. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2); gradational contacts with units above and below		9
101. Mudstone, massive, brownish-gray (5*YR* 4/1); weathers to light brownish gray (5*YR* 6/1)	24	8
100. Covered interval—probably mudstone, brownish-gray	109	1
99. Sandstone, volcanic, medium-bedded to massive, crossbedded, medium- to coarse-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); contains macerated plant fragments; ridge former; top 1 ft is thin bedded and fine grained; upper 7.5 ft is thin bedded	16	0
98. Covered interval—probably mudstone, olive-gray	105	0
97. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	4	6
96. Mudstone, massive, olive-gray (5*Y* 3/2); weathers to light olive gray (5*Y* 5/2); poorly exposed	70	11
95. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to medium-grained, poorly sorted, dark-yellowish-brown (10*YR* 4/2); weathers to pale		

SECTION 18—Continued

Type section of the Billman Creek Formation of the Livingston Group, measured in the W½ sec. 18, T. 2 S., R. 9 E., and the S½ sec. 13, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Billman Creek Formation—Continued	Ft	In.
yellowish brown (10*YR* 6/2); lower 1 ft is composed of granules and are mudstone pebbles as much as 2 in. in diameter	8	0
94. Mudstone, massive, silty, dark-yellowish-brown (10*YR* 4/2); weathers to pale yellowish brown (10*YR* 6/2); poorly exposed	24	4
93. Sandstone, volcanic, massive, crossbedded, fine- to medium-grained, poorly sorted, light-brownish-gray (5*YR* 6/1); weathers to light olive gray (5*Y* 6/1); contains small scour-and-fill channels and bedding often marked by thin (less than ⅛ in.) layers of ferromagnesian minerals	6	7
92. Siltstone, massive, clayey, brownish-gray (5*YR* 4/1); weathers to light brownish gray (5*YR* 6/1); poorly exposed	12	5
91. Sandstone, volcanic, massive, crossbedded, fine- to medium-grained, poorly sorted (contains some disseminated granules), andesitic, light-brownish-gray (5*YR* 6/1); weathers to light olive gray (5*Y* 6/1)	8	0
90. Covered interval—probably mudstone, brownish-gray	50	6
89. Sandstone, volcanic, thick-bedded, coarse-grained, poorly sorted, andesitic, olive-gray (5*Y* 4/1); weathers to brownish gray (5*YR* 4/1)	2	2
88. Sandstone, volcanic, massive, crossbedded, fine-grained, andesitic, pale-yellowish-brown (10*YR* 6/2); weathers to light brownish gray (5*YR* 6/1)	4	9
87. Covered interval—probably mudstone, brownish-gray	38	0
86. Sandstone, volcanic, massive, crossbedded, fine-grained, andesitic, pale-yellowish-brown (10*YR* 6/2); weathers to light brownish gray (5*YR* 6/1)	11	6
85. Covered interval—probably mudstone, brownish-gray	10	9
84. Sandstone, volcanic, massive, crossbedded, fine-grained, andesitic, pale-yellowish-brown (10*YR* 6/2); has banded character imparted by very thin (less than 1/16 in.) layers of ferromagnesian minerals on bedding planes; weathers to light brownish gray (5*YR* 6/1); ridge former	4	6
83. Covered interval—probably mudstone, brownish-gray	12	0
82. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	7	3
81. Mudstone, massive, brownish-gray (5*YR* 4/1); weathers to light brownish gray (5*YR* 6/1)	24	2

SECTION 18—Continued

Type section of the Billman Creek Formation of the Livingston Group, measured in the W½ sec. 18, T. 2 S., R. 9 E., and the S½ sec. 13, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Billman Creek Formation—Continued	Ft	In.
80. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, medium-light-gray (*N*6); weathers to light olive gray (5*Y* 6/1)	1	4
79. Covered interval—probably mudstone, brownish-gray	26	10
78. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, medium-light-gray (*N*6); weathers to light olive gray (5*Y* 6/1)		10
77. Mudstone, massive, brownish-gray (5*YR* 4/1); weathers to light brownish gray (5*YR* 6/1)	8	1
76. Sandstone, volcanic, massive, crossbedded, fine-grained, andesitic, medium-light-gray (*N*6), has banded character imparted by thin (less than 1/16 in.) layers of ferromagnesian minerals on bedding planes; weathers to light olive gray (5*Y* 6/1)	5	0
75. Claystone, massive, brownish-gray (5*YR* 4/1); weathers to light olive gray (5*Y* 6/1)	6	6
74. Sandstone, volcanic, massive, medium- to coarse-grained, very poorly sorted, andesitic, medium-light-gray (*N*6); weathers to light gray (*N*7)	4	7
73. Mudstone, massive, brownish-gray (5*YR* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed; USGS Paleobotany loc. D1614	31	10
72. Sandstone, volcanic, massive, medium- to coarse-grained, very poorly sorted (contains rare pebbles of volcanic rock), andesitic, medium-light-gray (*N*6); weathers to light gray (*N*7)	8	8
71. Mudstone, massive, interbedded grayish-red (5*R* 4/2) and grayish-green (10*GY* 5/2); weathers to pale red (5*R* 6/2) and grayish yellow green (5*GY* 7/2); poorly exposed	59	7
70. Sandstone, volcanic, medium-bedded, very fine grained, andesitic, medium-dark-gray (*N*4); weathers to brownish gray (5*YR* 4/1)	1	9
69. Claystone, medium-bedded, very dusky red (10*R* 2/2); weathers to grayish red (5*R* 4/2)	1	6
68. Sandstone, volcanic, medium-bedded, very fine grained, andesitic, medium-dark-gray (*N*4); weathers to brownish gray (5*YR* 4/1)	1	11
67. Claystone, medium-bedded, very dusky red (10*R* 2/2); weathers to grayish red (5*R* 4/2)	1	4
66. Sandstone, volcanic, massive, very fine grained, andesitic, medium-dark-gray (*N*4); weathers to brownish gray (5*YR* 4/1)	4	0
65. Claystone, medium-bedded, very dusky red (10*R* 2/2); weathers to grayish red (5*R* 4/2)	2	8

SECTION 18—Continued

Type section of the Billman Creek Formation of the Livingston Group, measured in the W½ sec. 18, T. 2 S., R. 9 E., and the S½ sec. 13, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Billman Creek Formation—Continued	Ft	In.
64. Sandstone, volcanic, medium-bedded, very fine grained, andesitic, medium-dark-gray (*N*4); weathers to brownish gray (5*YR* 4/1)	1	0
63. Mudstone, massive, very dusky red (10*R* 2/2); weathers to grayish red (5*R* 4/2)	16	1
62. Covered interval—probably mudstone, grayish-red and dusky-yellow-green	49	1
61. Claystone, thick-bedded, mottled dusky-yellow-green (5*GY* 5/2) and grayish-red (5*R* 4/2); weathers to grayish yellow green (5*GY* 7/2) and pale red (5*R* 6/2)	3	0
60. Sandstone, volcanic, massive, fine- to medium-grained, silty, poorly sorted, andesitic, mottled dusky-yellow-green (5*GY* 5/2) and grayish-red (5*R* 4/2); weathers to grayish yellow green (5*GY* 7/2) and pale red (5*R* 6/2)	6	10
59. Mudstone, massive, very dusky red (10*R* 2/2); weathers to grayish red (5*R* 4/2)	8	1
58. Sandstone, volcanic, massive, crossbedded, fine- to coarse-grained, andesitic, pale-red (5*R* 6/2); weathers to light brownish gray (5*YR* 6/1); channel-fill deposit that cuts 13 ft into underlying siltstone; contains rapid lateral changes in grain size and interfingers with grayish-red mudstone	17	6
57. Siltstone, massive, olive-gray (5*Y*4/1); weathers to light olive gray (5*Y* 5/2); overlying sandstone fills a channel cut 13 ft deep into this unit	26	4
56. Sandstone, volcanic, medium-bedded, fine-grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2)		10
55. Siltstone, thin-bedded, dusky-yellow-green (5*GY* 5/2); weathers to light greenish gray (5*GY* 8/1); brecciated and cemented with gypsum		3
54. Mudstone, medium-bedded, grayish-red (10*R* 4/2); weathers to pale red (10*R* 6/2)	1	5
53. Sandstone, volcanic, medium-bedded, very fine grained, andesitic, pale-red (5*R* 6/2); contains red specks of heulandite; weathers to light brownish gray (5*YR* 6/1)	1	9
52. Sandstone, volcanic, massive, fine- to coarse-grained, very poorly sorted, andesitic, pale-red (5*R* 6/2); weathers to light brownish gray (5*YR* 6/1); scour-and-fill deposits that contain small pebbles of mudstone and volcanic rock in lower half; generally thin bedded and fine grained in upper half	6	10
51. Covered interval—probably mudstone, very dusky red	227	6
50. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine to medium-grained, poorly sorted, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to dark yellowish brown (10*YR* 4/2); ridge former	12	8
49. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	26	1
48. Sandstone, volcanic, thin- to medium-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	13	0
47. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	48	2
46. Sandstone, volcanic, thin- to medium-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); ridge former	8	0
45. Mudstone, massive, very dusky red (10*R* 2/2); weathers to grayish red (5*R* 4/2)	18	8
44. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, olive-gray (5*Y* 4/1); weathers to dark yellowish brown (10*YR* 4/2)	1	2
43. Mudstone, massive, very dusky red (10*R* 2/2); weathers to grayish red (5*R* 4/2)	14	8
42. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, medium-light-gray (*N*6); weathers to light gray (*N*7)	1	8
41. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	7	10
40. Siltstone, thin-bedded, well-indurated, dark-gray (*N*3); contains red specks of heulandite; weathers to greenish gray (5*GY* 6/1)		4
39. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains red specks of heulandite	7	4
38. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains abundant bronze-colored biotite		2
37. Siltstone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains red specks of heulandite	1	2
36. Sandstone, volcanic, medium- to thick-bedded, crossbedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); has banded character imparted by thin (less than 1/16 in.) layers of ferromagnesian minerals on bedding planes; weathers to light olive gray (5*Y* 5/2); contains abundant bronze-colored biotite	6	3
35. Claystone, massive, greenish-gray (5*GY* 6/1); weathers to light greenish gray (5*GY* 8/1)	9	4
34. Sandstone, volcanic, thin- to medium-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); ridge former	6	8
33. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to greenish gray (5*GY* 6/1)	9	0

441-754 O - 72 - 7

SECTION 18—Continued

Type section of the Billman Creek Formation of the Livingston Group, measured in the W½ sec. 18, T. 2 S., R. 9 E., and the S½ sec. 13, T. 2 S., R. 8 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Billman Creek Formation—Continued	Ft	In.
32. Sandstone, volcanic, massive in lower half and thin- to medium-bedded in upper half, fine- to coarse-grained, poorly sorted (pebbles of volcanic rock are rare to common), dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	9	2
31. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	45	5
30. Sandstone, volcanic, massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); contains some calcareous concretions in the upper half	19	6
29. Covered interval—probably mudstone, dusky-yellow-green	28	1
28. Sandstone, volcanic, medium- to thick-bedded, fine- to medium-grained, andesitic, dusky-yellow-green (5*GY* 5/2); contains abundant diopsidic augite; weathers to grayish yellow green (5*GY* 7/2)	8	10
27. Mudstone, thick-bedded, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	3	6
26. Sandstone, volcanic, thin- to medium-bedded, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	10	0
25. Mudstone, massive, brownish-gray (5*YR* 4/1); weathers to light brownish gray (5*YR* 6/1)	9	1
24. Sandstone, volcanic, massive, crossbedded, fine- to medium-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); lower 2 ft is poorly sorted, coarse-grained sandstone, which contains grains as large as granules; some calcareous concretions in upper 3 ft	15	0
23. Mudstone, massive, brownish-gray (5*YR* 4/1); weathers to light brownish gray (5*YR* 6/1)	22	0
22. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, grayish-green (10*GY* 5/2); weathers to yellowish gray (5*Y* 7/2); contains calcareous concretions	8	10
21. Mudstone, massive, brownish-gray (5*YR* 4/1); weathers to light brownish gray (5*YR* 6/1)	14	4
20. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, medium-gray (*N*5); weathers to light olive gray (5*Y* 6/1)	2	1
19. Mudstone, massive, brownish-gray (5*YR* 4/1); weathers to light brownish gray (5*YR* 6/1)	10	7
18. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, grayish-green (10*GY* 5/2); weathers to yellowish gray (5*Y* 7/2)	6	0
17. Mudstone, massive, brownish-gray (5*YR* 4/1); weathers to light brownish gray (5*YR* 6/1)	21	2
16. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, grayish-green (10*GY* 5/2); weathers to yellowish gray (5*Y* 7/2); ridge former	13	0
15. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	15	0
14. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine-grained, andesitic, grayish-green (10*GY* 5/2); weathers to light olive gray (5*Y* 5/2); contains a few calcareous concretions; ridge former	10	1
13. Siltstone, massive, clayey, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2)	12	3
12. Sandstone, volcanic, medium-bedded, medium- to coarse-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 8/1)	10	0
11. Siltstone, massive, moderate-olive-brown (5*Y* 4/4); weathers to dusky yellow (5*Y* 6/1)	5	2
10. Sandstone, volcanic thick-bedded to massive, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2); locally conglomeratic at base, where it contains granules and pebbles (as much as 0.5 in. in diameter) of volcanic rocks; ridge former	13	0
9. Siltstone, massive, moderate-olive-brown (5*Y* 4/4); weathers to dusky yellow (5*Y* 6/4)	19	2
8. Sandstone, volcanic, massive, crossbedded, fine- to medium-grained, andesitic, medium-light-gray (*N*6); weathers to light gray (*N*7) and to very light gray (*N*8); slight tendency to form ridges	17	8
7. Mudstone, massive, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2)	7	3
6. Sandstone, volcanic, thin- to medium-bedded, fine-grained, andesitic, grayish-green (10*GY* 5/2); contains abundant diopsidic augite; weathers to pale yellowish green (10*GY* 7/2)	9	2
5. Claystone, massive, grayish-red (5*R* 4/2); weathers to pale red (5*R* 6/2)	7	5
4. Sandstone, volcanic, thin- to thick-bedded, fine- to medium-grained, andesitic, dark-greenish-gray (5*GY* 4/1); weathers to greenish gray (5*GY* 6/1); contains macerated plant fragments	5	3

SECTION 18—Continued

Type section of the Billman Creek Formation of the Livingston Group, measured in the W½ sec. 18, T. 2 S., R. 9 E., and the S½ sec. 13, T. 2 S., R. 8 E., Park County, Mont.—Continued

	Ft	In.
Upper Cretaceous—Livingston Group—Billman Creek Formation—Continued		
3. Siltstone, very thin bedded, grayish-olive (10*Y* 4/2); weathers to light olive gray (5*Y* 5/2); contains abundant macerated plant fragments	2	7
2. Sandstone, volcanic, thick-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, calcareous, medium-gray (*N*5); weathers to light olive gray (5*Y* 5/2); contains abundant diopsidic augite; contains abundant calcareous concretions, which are spherical (fig. 19) and persistent laterally; along some bedding planes are layers (a few inches thick) of granule and pebble conglomerate and layers of mudstone; most pebbles are mudstone but some are volcanic rock; concretions weather to grayish brown (5*YR* 3/2); ridge former	19	2
1. Mudstone, massive, grayish-brown (5*YR* 3/2) and grayish-green (10*GY* 5/2); weathers to pale brown (5*YR* 5/2)	95	9
Total thickness of Billman Creek Formation	2, 590	0
Upper Cretaceous—Livingston Group—Miner Creek Formation.		

HOPPERS FORMATION

Stratigraphic section 19 of the Hoppers Formation of the Livingston Group, measured near Hoppers Station northeast of the abandoned townsite of Cokedale, Mont. (sections 8 and 9, fig. 15), is the type section of the formation.

SECTION 19

Type section of the Hoppers Formation of the Livingston Group, measured in the SW¼ sec. 7 and the NW¼ sec. 18, T. 2 S., R. 9 E., Park County, Mont.

[Measured by A. E. Roberts and A. L. Benson, 1961]

	Ft	In.
Upper Cretaceous and Paleocene—Fort Union Formation.		
Upper Cretaceous—Livingston Group—Hoppers Formation:		
52. Sandstone, volcanic, massive, crossbedded, coarse-grained, very poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1) and yellowish gray (5*Y* 7/2); cliff former	30	0
51. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	15	1
50. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1)	13	10

SECTION 19—Continued

Type section of the Hoppers Formation of the Livingston Group, measured in the SW¼ sec. 7 and the NW¼ sec. 18, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Upper Cretaceous—Livingston Group—Hoppers Formation—Continued		
49. Siltstone, massive, olive gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	7	0
48. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, very poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); contains many layers of coarse grains to granules; contains a few layers composed of small pebbles of volcanic rock and mudstone; slight tendency to form ridges	49	1
47. Siltstone, massive, olive gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	44	7
46. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1)	7	0
45. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	40	9
44. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); upper 10 ft well-indurated	26	3
43. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	13	9
42. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); USGS Paleobotany loc. D4104–C	15	4
41. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	16	2
40. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to greenish gray (5*GY* 6/1); contains wood and plant fragments	33	6
39. Siltstone, thick-bedded, dusky-yellow-green (5*GY* 5/2); weathers to greenish gray (5*GY* 6/1)	3	1
38. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to greenish gray (5*GY* 6/1)	32	5
37. Sandstone, thick-bedded, very fine grained, silty, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	3	4
36. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); contains wood and plant fragments; a 5-ft-thick zone in middle of unit is poorly sorted, coarse-grained to granule sandstone that contains many mudstone balls and some volcanic rock pebbles	40	10

SECTION 19—Continued

Type section of the Hoppers Formation of the Livingston Group, measured in the SW¼ sec. 7 and the NW¼ sec. 18, T. 2 S., R. 9 E., Park County, Mont.—Continued

Upper Cretaceous—Livingston Group—Hoppers Formation—Continued	Ft	In.
35. Siltstone, thick-bedded, clayey, very calcareous (contains small calcareous concretions), brownish-black (5*YR* 2/1); weathers to light brownish gray (5*YR* 6/1); USGS Mesozoic loc. 28592	3	9
34. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained poorly sorted, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	40	2
33. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	7	7
32. Sandstone, volcanic, thin-bedded to massive, fine- to medium-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); contains wood and plant fragments	44	0
31. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains calcareous concretions	21	3
30. Sandstone, volcanic, thin-bedded, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1)	10	0
29. Siltstone, medium-bedded, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1)	2	0
28. Sandstone, volcanic, thin-bedded to massive, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); contains small rare calcareous concretions; contains some petrified wood; ridge former	43	3
27. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	6	9
26. Sandstone, volcanic, thin- to thick-bedded, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1)	3	10
25. Claystone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	3	9
24. Sandstone, volcanic, thin-bedded to massive, fine- to coarse-grained, poorly sorted, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1)	32	2
23. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	7	6
22. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1)	1	8
21. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	13	2
20. Sandstone, volcanic, massive, crossbedded, bedded, fine- to medium-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1)	12	4
19. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	30	0
18. Sandstone, volcanic, thin-bedded to massive, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	29	2
17. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	7	11
16. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	1	6
15. Siltstone, thick-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	2	10
14. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); ridge former	15	0
13. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	65	4
12. Sandstone, volcanic, thin-bedded, crossbedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); poorly exposed	8	6
11. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	17	7
Total Hoppers Formation that lies above the basal sandstone member	823	0
Basal sandstone member:		
10. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, very poorly sorted (contains thin to medium conglomeratic beds composed of small mudstone pebbles), andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to a conspicuous yellowish gray (5*Y* 7/2): has banded character imparted by thin (less than 0.25 in.) layers of ferromagnesian minerals on bedding planes; large massive speroidal weathering; thin-bedded part is finer grained and commonly more calcareous then rest of unit, and it is commonly cut out by the overlying massive sandstone; cliff former; contains some wood and plant imprints	74	6
9. Mudstone, thick-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	7	4

SECTION 19—Continued

Type section of the Hoppers Formation of the Livingston Group, measured in the SW¼ sec. 7 and the NW¼ sec. 18, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Upper Cretaceous—Livingston Group—Hoppers Formation—Continued		
Basal sandstone member—Continued		
8. Sandstone, volcanic, thin-bedded, fine- to medium-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2)	2	9
7. Siltstone, thick-bedded, clayey, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	2	8
6. Sandstone, volcanic, thin-bedded, fine- to medium-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2)	1	4
5. Claystone, thick-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	3	8
4. Sandstone, volcanic, thin-bedded, fine- to medium-grained, andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2); eastward this unit merges with the underlying sandstone unit	9	2
3. Sandstone, volcanic, massive, crossbedded, very poorly sorted, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2); composed of coarse grains to granules; locally conglomeratic, containing small mudstone pebbles; ridge former	5	2
2. Mudstone, thick-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains a few calcareous concretions; this unit is cut out to the east, where the overlying and underlying sandstones form a large cliff	16	6
1. Sandstone, volcanic, massive, crossbedded, thin-bedded locally in upper part, fine-grained, andesitic, slightly calcareous in upper part, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2); contains rare mudstone balls in lower part	18	11
Total thickness of basal sandstone member	142	0
Total thickness of Hoppers Formation	965	0
Upper Cretaceous—Livingston group—Billman Creek Formation.		

FORT UNION FORMATION

Stratigraphic section 20 of the Fort Union Formation is considered to be typical of the formation in the area west of Livingston and is here designated a reference section. This section was measured north of Hoppers Station near the abandoned townsite of Cokedale, Mont. (sections 10–18, fig. 15). The section at this locality is the most complete (contains the youngest beds of the formation in the western part of the Crazy Mountains basin).

SECTION 20

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.

[Measured by A. E. Roberts and A. L. Benson, 1961]

	Ft	In.
Paleocene—Fort Union Formation:		
Topmost section of formation removed by erosion.		
Upper conglomeratic sandstone member:		
242. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to medium-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); commonly contains pebbles of volcanic rock, quartzite, gneiss, and limestone; contains wood and plant fragments; ridge former	23	0
241. Covered interval—probably siltstone, similar to underlying unit	130	0
240. Siltstone, thin-bedded to massive, sandy, locally calcareous, light-olive-gray (5*Y* 5/2); weathers to yellowish gray (5*Y* 7/2); contains abundant calcareous concretions less than 1 ft in diameter	26	6
239. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained (commonly contains pebbles of volcanic rock, quartzite, gneiss, and limestone), andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains a few interbedded very fine grained silty sandstones; contains wood and plant fragments; ridge former	53	0
238. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, light-olive-gray (5*Y* 5/2); weathers to light olive gray (5*Y* 6/1); contains rare volcanic rock pebbles; contains wood and plant fragments; ridge former	15	0
237. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, light-olive-gray (5*Y* 5/2); weathers to light olive gray (5*Y* 6/1); contains a few calcareous concretions as much as 6 in. in diameter (generally 2 in.); grades upward into siltstone in upper part; poorly exposed	26	4
236. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains a few sporadic pebbles of volcanic rock; contains wood and plant fragments; ridge former	40	0

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Paleocene—Fort Union Formation—Continued		
Upper conglomeratic sandstone member—Con.		
235. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, noncalcareous, light-olive-gray (5*Y* 5/2); weathers to light olive gray (5*Y* 6/1); poorly exposed	18	4
234. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains wood and plant fragments; ridge former	13	0
233. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, noncalcareous, light-olive-gray (5*Y* 5/2); weathers to light olive gray (5*Y* 6/1); poorly exposed	67	8
232. Sandstone, volcanic, massive, fine- to medium-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains rare pebbles of volcanic rock; contains wood and plant fragments	11	0
231. Covered interval—probably very fine grained noncalcareous sandstone	156	0
230. Sandstone, volcanic, thin-bedded, fine- to coarse-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); ridge former	36	0
229. Covered interval—probably very fine grained sandstone	62	0
228. Sandstone, volcanic, thin-bedded, fine- to coarse-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); poorly exposed in upper part	48	0
227. Covered interval—probably very fine grained sandstone	47	0
226. Sandstone, volcanic, thin-bedded, fine- to coarse-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains interbedded very fine grained silty sandstone; slight tendency to form ridges	120	0
225. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, light-olive-gray (5*Y* 5/2); weathers to light olive gray (5*Y* 6/1); poorly exposed	22	3
224. Sandstone, volcanic, thin-bedded, crossbedded, fine- to coarse-grained, andesitic; contains sporadic pebbles and cobbles of volcanic rock, granite,		

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Paleocene—Fort Union Formation—Continued		
Upper conglomeratic sandstone member—Con.		
quartzite, welded tuff, and clay; calcareous in upper 10 ft.; greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains wood and plant fragments; slight tendency to form ridges	66	0
223. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, locally calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains interbedded fine-grained silty sandstone	64	0
222. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, locally calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); locally contains layers—generally at the bottom of a channel deposit—of pebbles and cobbles of volcanic rock, quartzite, and gneiss; contains wood and plant fragments; very calcareous continuously in upper 20 ft., which makes it a very good ridge former	111	6
221. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, light-olive-gray (5*Y* 5/2); weathers to light olive gray (5*Y* 6/1)	8	2
220. Sandstone, volcanic, thin-bedded to massive (generally thin-bedded), crossbedded, fine-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	18	4
219. Covered interval—probably very fine grained sandstone	29	6
218. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted (commonly contains pebbles and cobbles of volcanic rock, quartzite, and gneiss), andesitic, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); poorly exposed	34	6
217. Covered interval—probably very fine grained sandstone	22	0
216. Sandstone, volcanic, thin-bedded to massive (generally thin-bedded), crossbedded, fine-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	31	6

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Paleocene—Fort Union Formation—Continued	Ft	In.
Upper conglomeratic sandstone member—Con.		
215. Covered interval—probably very fine grained sandstone	46	0
214. Sandstone, volcanic, thin-bedded to massive (generally thin-bedded), crossbedded, fine-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	38	6
213. Covered interval—probably very fine grained sandstone	31	0
212. Sandstone, volcanic, thin-bedded to massive (generally thin-bedded), crossbedded, fine-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2) slight tendency to form ridges	23	2
211. Covered interval—probably very fine grained sandstone	49	6
210. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	4	8
209. Covered interval—probably very fine grained sandstone	17	4
208. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	14	0
207. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic. light-olive-gray (5*Y* 5/2); weathers to light olive gray (5*Y* 6/1); poorly exposed	24	0
206. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	1	0
205. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, locally, calcareous greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains sporadic pebbles, cobbles, and boulders of volcanic rock, quartzite, and gneiss; poorly exposed	99	0
204. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	18	0

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Paleocene—Fort Union Formation—Continued	Ft	In.
Upper conglomeratic sandstone member—Con.		
203. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, light-olive-gray (5*Y* 5/2); weathers to light olive gray (5*Y* 6/1); poorly exposed	21	7
202. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	35	0
201. Claystone, thick-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	3	10
200. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, light-olive-gray (5*Y* 5/2); weathers to light olive gray (5*Y* 6/1)	16	10
199. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains pebbles, cobbles, and boulders of volcanic rock, quartzite, and gneiss—generally along the base of channel deposits; ridge former	56	0
Total measured upper conglomeratic sandstone member	1,800	0
Middle sandstone and mudstone member:		
198. Covered interval—probably yellowish-gray siltstone	64	0
197. Sandstone, volcanic, thin-bedded to massive (dominantly thin-bedded and fine-grained), fine- to coarse-grained (contains sporadic pebbles of volcanic rock and mudstone), andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); cliff former	87	6
196. Siltstone, massive, clayey, grayish-green (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1); contains macerated plant fragments	38	4
195. Sandstone, volcanic, thin-bedded to massive (dominantly thin-bedded and fine-grained), fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains layers of mudstone pebbles	20	0
194. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	14	3

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Paleocene—Fort Union Formation—Continued		
Middle sandstone and mudstone member—Con.		
193. Sandstone, volcanic, thin-bedded to massive, fine- to coarse-grained (dominantly thin-bedded and fine-grained), andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	25	0
192. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	18	9
191. Sandstone, volcanic, thin-bedded to massive, fine- to coarse-grained (dominantly fine-grained and thin-bedded), andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); ridge former	36	0
190. Sandstone, volcanic, massive, very fine grained, silty, andesitic, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); very poorly exposed	98	0
189. Sandstone, volcanic, massive, crossbedded, medium- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	28	0
188. Sandstone, volcanic, thin-bedded, crossbedded, fine-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight ridge former	19	0
187. Claystone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	1	4
186. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained (dominantly thin-bedded and fine-grained), andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	26	9
185. Covered interval—probably mudstone that has about 10 ft of thin-bedded, medium-grained sandstone in the middle	67	0
184. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	50	0
183. Claystone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	44	0

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Paleocene—Fort Union Formation—Continued		
Middle sandstone and mudstone member—Con.		
182. Sandstone, volcanic, thin-bedded, cross-bedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	12	0
181. Covered interval—probably massive olive-gray mudstone	90	0
180. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); ridge former	55	0
179. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	22	8
178. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains local zones of mudstone pebbles; contains wood and plant fragments; ridge former	50	0
177. Sandstone, volcanic, massive, very fine grained, silty, andesitic, micaceous, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*GY* 6/1); contains macerated plant fragments; poorly exposed	13	9
176. Claystone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains dark-olive-gray (5*Y* 3/1) calcareous concretions as much as 6 in. in diameter; poorly exposed	40	0
175. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic; contains local zones of mudstone pebbles; slightly calcareous; greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains wood and plant fragments; ridge former	50	0
174. Sandstone, volcanic, massive, very fine grained, silty, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1)	10	0
173. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic; contains local zones of mudstone pebbles; slightly calcareous; greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains wood and plant fragments; ridge former	38	9

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Paleocene—Fort Union Formation—Continued

Middle sandstone and mudstone member—Con.	*Ft*	*In.*
172. Siltstone, massive, sandy, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1)	14	6
171. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	28	0
170. Sandstone, volcanic, massive, very fine grained, silty, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1); grades upward into the overlying mudstone	9	0
169. Mudstone, thick-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	3	9
168. Sandstone, volcanic, massive, fine- to coarse-grained, andesitic, calcareous in middle, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	5	0
167. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	4	0
166. Sandstone, volcanic, massive, very fine grained, silty, andesitic, calcareous in upper 2 ft., greenish-gray (5G*Y* 6/1); weathers to light olive gray (5*Y* 6/1)	6	0
165. Mudstone, massive, calcareous, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	13	0
164. Sandstone, volcanic, thick-bedded, very fine grained, silty, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1)	2	8
163. Siltstone, medium-bedded, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1)	1	9
162. Limestone, dense, microcrystalline, medium-gray (*N*5); weathers to light olive gray (5*Y* 6/1); probably of fresh-water origin		4
161. Mudstone, massive, calcareous, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains calcareous concretions as much as 8 in. in diameter	12	2
160. Siltstone, thick-bedded, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1)	2	0
159. Sandstone, volcanic, thick-bedded, very fine grained, silty, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1); gradational into overlying siltstone	3	0
158. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, very calcareous, greenish-gray (5*GY* 6/1); weathers		

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Paleocene—Fort Union Formation—Continued

Middle sandstone and mudstone member—Con.	*Ft*	*In.*
to yellowish gray (5*Y* 7/2); contains calcareous concretions in upper part	15	0
157. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, locally conglomeratic in lower part (containing pebbles of volcanic rock and mudstone), thin-bedded and fine-grained in upper part, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight ridge former	9	0
156. Covered interval—probably very fine grained sandstone	4	0
155. Sandstone, volcanic, thin-bedded, slightly crossbedded, fine- to coarse-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains wood fragments; slight tendency to form ridges	45	0
154. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained. andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	12	4
153. Sandstone, volcanic, massive, very fine grained, silty, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1)	18	4
152. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained (coarse in lower part grading upward to fine), andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	13	9
151. Sandstone, volcanic, thin-bedded to massive, crossbedded. fine- to medium-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	6	10
150. Covered interval—probably very fine grained sandstone	32	6
149. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	4	0
148. Sandstone, volcanic, massive, very fine grained, silty, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1)	10	6

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Paleocene—Fort Union Formation—Continued

Middle sandstone and mudstone member—Con.	Ft	In.
147. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to medium-grained, andesitic, slightly calcareous in upper part; greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2) in upper part and yellowish gray (5*Y* 7/2) in lower part; ridge former	26	0
146. Sandstone, volcanic, thick-bedded, very fine grained, silty, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1); contains macerated plant fragments	3	2
145. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	1	8
144. Sandstone, volcanic, massive, fine-grained, andesitic, greenish-gray (5 *GY* 6/1); weathers to light olive gray (5*Y* 6/1); contains macerated plant fragments	15	0
143. Sandstone, volcanic, thin- to thick-bedded, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	4	4
142. Sandstone, volcanic, massive, very fine grained, silty, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1)	6	0
141. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); ridge former	18	0
140. Sandstone, volcanic, massive, very fine grained, silty, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	8	0
139. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	23	4
138. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); upper part thin bedded; contains wood fragments; ridge former	65	0

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Paleocene—Fort Union Formation—Continued

Middle sandstone and mudstone member—Con.	Ft	In.
137. Sandstone, volcanic, massive, very fine grained, silty, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	35	8
136. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	19	3
135. Sandstone, volcanic, thin-bedded, slightly crossbedded, fine-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1)	5	0
134. Sandstone, volcanic, thick-bedded, very fine grained, silty, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1)	3	9
133. Sandstone, volcanic, thin-bedded to massive, fine- to medium-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	22	0
132. Sandstone, volcanic, massive, very fine grained, silty, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	11	8
131. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	22	4
130. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	11	3
129. Sandstone, volcanic, thin-bedded to massive, fine- to coarse-grained, interbedded with very fine grained massive sandstone, andesitic, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); forms slabby rubble on slope; poorly exposed	72	6
128. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	18	0
127. Covered interval—probably very fine grained sandstone	44	6
126. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained (contains sporadic mudstone pebbles), andesitic, slightly calcareous, greenish-gray (5*GY* 6/1);		

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Paleocene—Fort Union Formation—Continued		
Middle sandstone and mudstone member—Con.	*Ft*	*In.*
(5*GY* 7/2) slight tendency to form ridges weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	15	0
125. Mudstone, massive, olive-gray (5*Y* 4/1) weathers to light olive gray (5*Y* 6/1); very poorly exposed	15	10
124. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained (contains sporadic mudstone pebbles), andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); ridge former	27	0
123. Sandstone, volcanic, massive, very fine grained, silty andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); contains macerated plant fragments; very poorly exposed	34	6
122. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); contains some layers of small pebbles of mudstone, volcanic rock, limestone, and quartzite; weathers to grayish yellow green (5*GY* 7/2); ridge former	15	0
121. Sandstone, volcanic, massive, very fine grained, micaceous, andesitic, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	11	0
120. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); ridge former	18	0
119. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); very poorly exposed	37	2
118. Sandstone, volcanic, thin-bedded to massive, fine- to coarse-grained, andestic, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains some layers of mudstone and volcanic rock pebbles	9	3
117. Claystone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)		8
116. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	1	0

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Paleocene—Fort Union Formation—Continued		
Middle sandstone and mudstone member—Con.	*Ft*	*In.*
115. Sandstone, volcanic, massive, fine-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to yellowish gray (5*Y* 7/2)	12	0
114. Sandstone, volcanic, thin-bedded, slightly crossbedded, medium- to coarse-grained, andesitic, locally calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	10	0
113. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	12	0
112. Sandstone, volcanic, thin-bedded to massive, crossbedded, medium- to coarse-grained, poorly sorted (contains sporadic mudstone pebbles), andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	18	3
111. Sandstone, volcanic, massive, fine-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to yellowish gray (5*Y* 7/2); massive spheroidal weathering	22	8
110. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained (generally coarse-grained), greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); ridge former	20	0
109. Sandstone, volcanic, massive, very fine grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); contains plant fragments; poorly exposed	55	3
108. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	12	4
107. Sandstone, volcanic, massive, very fine grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	9	8
106. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to light olive gray (5*Y* 5/2); ridge former	18	4
105. Sandstone, volcanic, massive, very fine grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); contains plant fragments	22	1

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Paleocene—Fort Union Formation—Continued

Middle sandstone and mudstone member—Con.	Ft	In.
104. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	20	1
103. Sandstone, volcanic, massive, very fine grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	9	9
102. Sandstone, volcanic, thin- to medium-bedded, medium- to coarse-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	4	8
101. Sandstone, volcanic, massive, very fine grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	8	0
100. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); ridge former	52	8
99. Claystone, thick-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	2	8
98. Sandstone, volcanic, thin-bedded to massive, crossbedded, medium- to coarse-grained, andesitic, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2)	11	3
97. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	23	2
96. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained (generally coarse-grained), andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); contains sporadic mudstone pebbles; thin bedded in upper part; slight tendency to form ridges	26	6
95. Sandstone, volcanic, massive, very fine grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); contains macerated plant fragments	17	0
94. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	35	9
93. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained (generally fine grained), andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1)	19	4

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Paleocene—Fort Union Formation—Continued

Middle sandstone and mudstone member—Con.	Ft	In.
92. Sandstone, volcanic, massive, very fine grained, silty, micaceous, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); poorly exposed	5	7
91. Sandstone, volcanic, thin-bedded to massive, slightly crossbedded, fine- to coarse-grained (generally fine-grained with fair sorting), andesitic, slightly calcareous, greenish-gray (5*GY* 6/1); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	17	6
90. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	26	8
89. Sandstone, volcanic, thin-bedded to massive, fine- to coarse-grained, very poorly sorted, andesitic, conglomeratic locally (containing pebbles of volcanic rock, quartzite, chert, and limestone), slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	25	0
88. Sandstone, volcanic, massive, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); poorly exposed	48	11
87. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); contains sporadic mudstone pebbles; ridge former	20	0
86. Sandstone, volcanic, massive, fine- to very fine-grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1)	20	2
85. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); ridge former	22	0
84. Sandstone, volcanic, massive, fine- to very fine-grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); poorly exposed	15	11
83. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, very poorly sorted, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); contains sporadic pebbles of volcanic rock; ridge former	35	0

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Paleocene—Fort Union Formation—Continued

Middle sandstone and mudstone member—Con.	Ft	In.
82. Siltstone, massive, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	38	8
81. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, locally calcareous, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); ridge former	83	6
80. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); locally clayey; contains macerated plant fragments	27	9
79. Sandstone, volcanic, medium-bedded, fine-grained, andesitic, calcareous, medium-light-gray (*N*6); weathers to light olive gray (5*Y* 5/2); contains macerated plant fragments	3	8
78. Siltstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains macerated plant fragments; USGS Paleobotany loc. D1784	4	2
77. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); locally contains channel-fill deposits of conglomeratic sandstone that bears pebbles and cobbles of volcanic rock, mudstone, quartzite, chert, and limestone; unit becomes more conglomeratic to the west; contains some crossbeds of granule-size grains; lower 62.5 ft poorly exposed; upper part is prominent ridge former	135	11
76. Siltstone, sandy, clayey, micaceous, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	15	9
75. Claystone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	3	6
74. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); contains plant fragments	20	0
73. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	32	9
72. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); channel-fill sands of varying grain size and color cut underlying beds of this unit; the coarser grained beds are darker in color than the finer grained beds; the poor sorting is generally in the coarse-grained beds; contains mudstone pebbles in bottoms of channel deposits; coarser grained part weathers to light olive gray (5*Y* 5/2) and finer grained part, to pale olive (10*Y* 6/2) to yellowish gray (5*Y* 7/2); massive spheroidal weathering; cliff former	108	0
71. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	9	4
70. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	17	3
69. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to pale olive (10*Y* 6/2); contains plant fragments; ridge former	20	0
68. Mudstone, massive, silty, slightly carbonaceous, olive-black (5*Y* 2/1); weathers to olive gray (5*Y* 4/1)	15	8
67. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2)	2	0
66. Siltstone, thick-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); contains plant fragments; USGS Paleobotany loc. D1783	2	3
65. Sandstone, volcanic, massive, crossbedded, medium- to coarse-grained, poorly sorted, andesitic, calcareous in upper part, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); massive spheroidal weathering in lower part; contains sporadic pebbles of volcanic rock and mudstone; contains crossbedded lenses of granule-size grains; contains plant fragments; ridge former	23	3
64. Siltstone, massive, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); very poorly exposed	59	10

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Paleocene—Fort Union Formation—Continued

Middle sandstone and mudstone member—Con.	Ft	In.
63. Sandstone, volcanic, medium-bedded to massive, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); contains sporadic pebbles of volcanic rock; ridge former	36	0
62. Sandstone, volcanic, thin-bedded, very fine grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); poorly exposed	50	11
61. Sandstone, volcanic, thin- to medium-bedded, fine- to coarse-grained, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	39	10
60. Siltstone, thin-bedded, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); poorly exposed	6	3
59. Sandstone, thin- to medium-bedded, fine- to coarse-grained, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); lower 12 ft poorly exposed	32	0
58. Siltstone, thin-bedded, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); contains macerated plant fragments	34	0
57. Sandstone, volcanic, medium-bedded to massive, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); contains sporadic pebbles of volcanic rock; ridge former	22	0
56. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	22	9
55. Sandstone, volcanic, thin-bedded to massive, crossbedded, coarse-grained to granule-size, very poorly sorted, andesitic, locally slightly calcareous, dusky-yellow-green (5*GY* 5/2); some crossbedded sands weather to grayish yellow green (5*GY* 7/2) and some weather to yellowish gray (5*Y* 7/2); the yellowish-gray beds have massive spheroidal weathering and are very conspicuous compared to the other unit; contains sporadic pebbles of volcanic rock and mudstone in channel-fill deposits; contains 1.5 ft siltstone bed in the middle	31	3
54. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	76	4

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Paleocene—Fort Union Formation—Continued

Middle sandstone and mudstone member—Con.	Ft	In.
53. Sandstone, volcanic, thin- to medium-bedded, crossbedded, medium- to coarse-grained, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); ridge former	27	6
52. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	28	3
51. Sandstone, volcanic, thin- to medium-bedded, crossbedded, medium-grained, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	1	10
50. Claystone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	2	0
49. Sandstone, volcanic, massive, crossbedded, generally coarse grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	5	0
48. Claystone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	1	0
47. Sandstone, volcanic, medium-bedded, medium- to coarse-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	1	4
46. Claystone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)		10
45. Sandstone, volcanic, thick-bedded, crossbedded, generally coarse grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	2	4
44. Claystone, medium-bedded, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)		9
43. Sandstone, volcanic, thin-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	3	4
42. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	52	2
41. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); contains fossil leaf prints; ridge former	40	0
40. Mudstone, massive, brownish-black (5*YR* 2/1); weathers to light olive gray (5*Y* 6/1)	13	1

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Paleocene—Fort Union Formation—Continued		
Middle sandsone and mudstone member—Con.		
39. Sandstone, volcanic, thin-bedded to massive, crossbedded, andesitic, very poorly sorted, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2) and yellowish gray (5*Y* 7/2); contains coarse-grained channel-fill deposits; contains some calcareous lenses; ridge former	61	0
38. Siltstone, thin-bedded, sandy, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1)	2	8
37. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to pale olive (10*Y* 6/2)	50	10
Total thickness of middle sandstone and mudstone member	3, 866	0
Upper Cretaceous—Fort Union Formation:		
Lower conglomeratic sandstone member:		
36. Sandstone, volcanic, thin- to medium-bedded, coarse-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); poorly indurated and poorly exposed	26	1
35. Sandstone, volcanic, thin- to medium-bedded, generally coarse grained, andestic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	8	9
34. Siltstone, massive, sandy, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 6/1); poorly exposed	20	11
33. Sandstone, volcanic, thin-bedded, generally fine grained (contains a few scattered layers of medium- to coarse-grained sand), andesitic, calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	15	0
32. Sandstone, volcanic, medium- to thick-bedded, coarse-grained, very poorly sorted (contains sporadic pebbles of volcanic rock and mudstone), slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); contains macerated plant fragments; ridge former	5	2
31. Siltstone, thin-bedded, sandy, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	3	0
30. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-		

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Upper Cretaceous—Fort Union Formation—Con.		
Lower conglomeratic sandstone member—Con.		
grained, very poorly sorted, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2); conglomeratic in channel-fill deposits which contain pebbles of volcanic rock and chert; the channel-fill beds are in the lower one-third of unit; above the channel-fill beds the unit gradually becomes fine grained and thin bedded, although still crossbedded; ridge former with unit 28	36	1
29. Siltstone, thin-bedded, sandy, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); contains macerated plant fragments; poorly exposed	1	8
28. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, very poorly sorted, andesitic, slightly calcareous, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2); conglomeratic in channel-fill deposits which contain pebbles of volcanic rock and chert	8	4
27. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1); poorly exposed	17	3
26. Sandstone, volcanic, thin-bedded, fine- to very fine grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to pale olive (10*Y* 6/2); poorly exposed	43	8
25. Sandstone, volcanic, thin- to medium-bedded, fine-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	3	2
24. Sandstone, volcanic, thin-bedded, fine- to very fine grained, silty, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to pale olive (10*Y* 6/2); contains macerated plant fragments; USGS Paleobotany locs. D1782 and D4105	8	8
23. Sandstone, volcanic, massive, cross-bedded, coarse-grained (contains sporadic pebbles of volcanic rock), very poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	12	0
22. Siltstone, massive, sandy, dusky-yellow-green (5*GY* 5/2); weathers to dusky yellow (5*Y* 6/4); poorly exposed	17	1

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

Upper Cretaceous—Fort Union Formation—Con.		
Lower conglomeratic sandstone member—Con.	*Ft*	*In.*
21. Sandstone, volcanic, thin-bedded to massive, crossbedded, very poorly sorted, conglomeratic (pebbles dominantly composed of volcanic rock and mudstone but include some white pumice fragments), dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); prominent ridge former	13	6
20. Sandstone, volcanic, massive, fine- to coarse-grained, crossbedded, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2); consists of channel-fill deposits that contain sporadic pebbles of volcanic rock	23	4
19. Sandstone, volcanic, thin-bedded to massive, fine- to coarse-grained, conglomeratic (pebbles dominantly composed of volcanic rock and mudstone), dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); slight ridge former	24	6
18. Sandstone, volcanic, massive, fine- to medium-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	6	0
17. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); contains fragments of petrified wood	29	0
16. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	77	4
15. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2)	25	0
14. Mudstone, massive, olive-gray (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	33	8
13. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); slight tendency to form ridges	16	3
12. Covered interval—probably dusky-yellow-green siltstone	52	9
11. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, contains a few thin channel-fill deposits that bear pebbles of volcanic rock and mudstone, dusky-yellow-green (5*GY* 7/2); cliff former	55	5
10. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine-grained to conglomeratic, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); contains channel-fill deposits that bear pebbles dominantly composed of volcanic rock and mudstone	12	4
9. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, andesitic, thin-bedded in upper 40 ft of unit, dusky-yellow-green (5*GY* 5/2); weathers to grayish yellow green (5*GY* 7/2); contains macerated plant fragments and small calcareous concretions; ridge former	60	0
8. Covered interval—probably dusky-yellow-green siltstone	137	0
7. Sandstone, volcanic, thin-bedded to massive, crossbedded, coarse-grained to conglomeratic, very poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); contains channel-fill deposits	24	0
6. Siltstone, massive, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2)	11	11
5. Sandstone, volcanic, thin-bedded to massive, crossbedded, fine- to coarse-grained, poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); contains wood and plant fragments	10	0
4. Siltstone, massive, dusky-yellow-green (5*GY* 5/2); weathers to yellowish gray (5*Y* 7/2); poorly exposed	39	10
3. Sandstone, volcanic, thin-bedded to massive, crossbedded, coarse-grained to conglomeratic, very poorly sorted, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2); unit is a channel-fill deposit; pebbles include andesites, intrusive porphyries, welded tuffs, Precambrian metamorphic rocks, and lesser amounts of Paleozoic and Mesozoic sedimentary rocks; many individual beds would be termed conglomerates; ridge former	45	0
2. Mudstone, massive, olive-gray, (5*Y* 4/1); weathers to light olive gray (5*Y* 6/1)	30	4
1. Sandstone, volcanic, thin-bedded to massive, crossbedded, coarse-grained to conglomeratic, very poorly sorted, andesitic, dusky-yellow-green (5*GY* 5/2); weathers to light olive gray (5*Y* 5/2);		

SECTION 20—Continued

Reference section of the Fort Union Formation, measured in secs. 7, 16, 17, 21, 28, 32, and 33, T. 1 S., R. 8 E.; secs. 2, 3, 11, 12, 13, and 23, T. 2 S., R. 8 E.; and secs. 7, 18, 19, and 20, T. 2 S., R. 9 E., Park County, Mont.—Continued

	Ft	In.
Upper Cretaceous—Fort Union Formation—Con.		
Lower conglomeratic sandstone member—Con.		
this is a channel-fill deposit that cuts into underlying units; cobbles and pebbles include andesites, intrusive porphyries, welded tuffs, Precambrian metamorphic rocks, and lesser amounts of Paleozoic and Mesozoic sedimentary rocks as much as 4 in. in diameter; ridge former	27	0
Total thickness of lower conglomeratic sandstone member	981	0
Total measured Fort Union Formation	6, 647	0

Upper Cretaceous—Livingston Group—Hoppers Formation.

REFERENCES CITED

Armstrong, F. C., and Oriel, S. S., 1965, Tectonic development of Idaho-Wyoming thrust belt: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 11, p. 1847–1866.

Berry, G. W., 1943, Stratigraphy and structure at Three Forks, Montana: Geol. Soc. America Bull., v. 54, no. 1, p. 1–30.

Billingsley, Paul, 1915, The Boulder batholith of Montana: Am. Inst. Mining Engineers Trans., v. 51, p. 31–47.

Bowen, C. F., 1918, Anticlines in a part of the Musselshell Valley, Musselshell, Meagher, and Sweetgrass Counties, Mont.: U.S. Geol. Survey Bull. 691–F, p. 185–209.

——— 1920, Gradations from continental to marine conditions of deposition in central Montana during the Eagle and Judith River epochs: U.S. Geol. Survey Prof. Paper 125–B, p. 11–21.

Bradley, W. H., 1930, The occurrence and origin of analcite and meerschaum beds in the Green River Formation of Utah, Colorado, and Wyoming: U.S. Geol. Survey Prof. Paper 158–A, 7 p.

Brown, C. W., 1957, Stratigraphic and structural geology of north central-northeast Yellowstone National Park, Wyoming and Montana: Princeton, N.J., Princeton Univ., Ph. D. thesis (available on microfilm from University Microfilms, Inc., Ann Arbor, Mich.).

——— 1961, Cenozoic stratigraphy and structural geology, northeast Yellowstone National Park, Wyoming and Montana: Geol. Soc. America Bull., v. 72, no. 8, p. 1173–1194.

Brown, R. W., 1939, Fossil plants from the Colgate Member of the Fox Hills Sandstone and adjacent strata: U.S. Geol. Survey Prof. Paper 189–I, p. 239–271.

——— 1946, Fossil plants and Jurassic-Cretaceous boundary in Montana and Alberta: Am. Assoc. Petroleum Geologists Bull., v. 30, no. 2, p. 238–248.

——— 1949, Paleocene deposits of the Rocky Mountains and Plains: U.S. Geol. Survey Mineral Resource Prelim. Map, scale 1:1,000,000.

——— 1962, Paleocene flora of the Rocky Mountains and Great Plains: U.S. Geol. Survey Prof. Paper 375, 119 p.

Calvert, W. R., 1908, The Lewistown coal field, Montana, *in* Part 2, Coal and lignite: U.S. Geol. Survey Bull. 341, p. 108–122.

——— 1912a, The Livingston and Trail Creek coal fields, Park, Gallatin, and Sweetgrass Counties, Montana, *in* Part 2, Mineral fuels: U.S. Geol. Survey Bull. 471, p. 384–405.

——— 1912b, The Electric coal field, Park County, Montana, *in* Part 2, Mineral fuels: U.S. Geol. Survey Bull. 471, p. 406–422.

——— 1917, Geology of the Upper Stillwater Basin, Stillwater and Carbon Counties, Montana, with special reference to coal and oil: U.S. Geol. Survey Bull. 641–G, p. 199–214.

Chadwick, R. A., 1969, The Northern Gallatin Range, Montana—northwestern part of the Absaroka-Gallatin volcanic field: Wyoming Univ. Contrib. Geology, v. 8, no. 2, pt. 2, p. 150–166 [1970].

Chamberlin, R. T., 1919, A peculiar belt of oblique faulting: Jour. Geology, v. 27, p. 602–613.

——— 1940, Diastrophic behavior around the Bighorn Basin: Jour. Geology, v. 48, p. 673–716.

Cobban, W. A., 1945, Marine Jurassic formations of Sweetgrass arch, Montana: Am. Assoc. Petroleum Geologists Bull., v. 29, no. 9, p. 1262–1303.

——— 1951, Colorado shale of central and northwestern Montana and equivalent rocks of Black Hills: Am. Assoc. Petroleum Geologists Bull., v. 35, no. 10, p. 2170–2198.

——— 1955, Cretaceous rocks of northwestern Montana *in* Billings Geol. Soc. Guidebook 6th Ann. Field Conf., Sweetgrass arch—Disturbed belt, Montana, September 1955: p. 107–119.

——— 1958, Late Cretaceous fossil zones of the Powder River Basin, Wyoming and Montana *in* Wyoming Geol. Assoc. Guidebook 13th Ann. Field Conf., Powder River Basin, 1958: p. 114–119.

——— 1962a, New baculites from the Bearpaw Shale and equivalent rocks of the Western Interior: Jour. Paleontology, v. 36, no. 1, p. 126–135.

——— 1962b, Baculites from the lower part of the Pierre Shale and equivalent rocks in the Western Interior: Jour. Paleontology, v. 36, no. 4, p. 704–718.

Cobban, W. A., and Reeside, J. B., Jr., 1951, Lower Cretaceous ammonites in Colorado, Wyoming, and Montana: Am. Assoc. Petroleum Geologists Bull., v. 35, no. 8, p. 1892–1893.

——— 1952a, Frontier Formation, Wyoming and adjacent areas: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 10, p. 1913–1961.

——— 1952b, Correlation of the Cretaceous formations of the Western Interior of the United States: Geol. Soc. America Bull., v. 63, no. 10, p. 1011–1044.

Cobban, W. A., Erdmann, C. E., Lemke, R. W., and Maughan, E. K., 1959, Revision of Colorado Group on Sweetgrass arch, Montana: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 12, p. 2786–2796.

Collier, A. J., 1922, The Osage oil field, Weston County, Wyoming: U.S. Geol. Survey Bull. 736–D, p. 71–110.

Darton, N. H., 1901, Preliminary description of the geology and water resources of the southern half of the Black Hills and adjoining regions in South Dakota and Wyoming: U.S. Geol. Survey 21st Ann. Rept., pt. 4, p. 489–599.

——— 1904, Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., v. 15, p. 379–448.

——— 1906, Geology of the Bighorn Mountains: U.S. Geol. Survey Prof. Paper 51, 129 p.

Darton, N. H., and O'Harra, C. C., 1909, Description of Belle Fourche quadrangle, South Dakota: U.S. Geol. Survey Geol. Atlas, Folio 164, 9 p.

Davis, W. M., 1886, Relation of the coal of Montana to the older rocks *in* Report on the mining industries of the United States, 1880: U.S. Census, 10th, v. 15, p. 697–712.

Dobbin, C. E., and Erdmann, C. E., 1955, Structure contour map of the Montana plains: U.S. Geol. Survey Oil and Gas Inv. Map OM–178A, scale 1 : 500,000.

Dobbin, C. E., and Horn, G. H., 1949, Geology of the Mush Creek and Osage oil fields and vicinity, Weston County, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map. 103, scale 1 inch to 2 miles (1 : 126,720).

Eicher, D. L., 1960, Stratigraphy and micropaleontology of the Thermopolis Shale [Wyoming]: Yale Univ., Peabody Mus. Nat. History Bull. 15, 126 p.

Eldridge, G. W., 1886, Montana coal fields *in* Report on the mining industries of the United States, 1880: U.S. Census, 10th, v. 15, p. 739–757, 781–789.

Fisher, C. A., 1908, Southern extension of the Kootenai and Montana coal-bearing formations in northern Montana: Econ. Geology, v. 3, no. 1, p. 77–99.

——— 1909, Geology of the Great Falls coal field, Montana: U.S. Geol. Survey Bull. 356, 85 p.

Foose, R. M., Wise, D. U., and Garbarini, G. S., 1961, Structural geology of the Beartooth Mountains, Montana and Wyoming: Geol. Soc. America Bull., v. 72, no. 8, p. 1143–1172.

Fox, S. K., Jr., 1939, The stratigraphy and micropaleontology of the Cody Shale in southern Montana and northern Wyoming: Princeton, N.J., Princeton Univ., Ph. D. thesis (available on microfilm from University Microfilms, Inc., Ann Arbor, Mich.).

Fraser, G. D., Waldrop, H. A., and Hyden, H. J., 1969, Geology of the Gardiner area, Park County, Montana: U.S. Geol. Survey Bull. 1277, 118 p.

Garbarini, G. S., 1957, Geology of the McLeod area, Beartooth Range, Montana: Princeton, N.J., Princeton Univ., Ph. D. thesis (available on microfilm from University Microfilms, Inc., Ann Arbor, Mich.).

Gardner, L. S., Hendricks, T. A., Hadley, H. D., and Rogers, C. P., 1945, Columnar sections of Mesozoic and Paleozoic rocks in the mountains of south-central Montana: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart. 18.

Gill, J. R., and Cobban, W. A., 1961, Stratigraphy of lower and middle parts of the Pierre Shale, northern Great Plains: U.S. Geol. Survey Prof. Paper 424–D, p. D185–D191.

——— 1962, Red Bird Silty Member of the Pierre Shale, a new stratigraphic unit: U.S. Geol. Survey Prof. Paper 450–B, p. B21–B24.

——— 1966, The Red Bird section of the Upper Cretaceous Pierre Shale in Wyoming: U.S. Geol. Survey Prof. Paper 393–A, 73 p.

Goddard, E. N., chm., and others, 1948, Rock-color chart: Washington, D.C., Natl. Research Council (repub. by Geol. Soc. America, 1951), 6 p.

Hackett, O. M., Visher, F. N., McMurtrey, R. G., and Steinhilber, W. L., 1960, Geology and ground-water resources of the Gallatin Valley, Gallatin County, Mont.: U.S. Geol. Survey Water-Supply Paper 1482, 282 p.

Hague, Arnold, Iddings, J. P., Weed, W. H., Walcott, C. D., Girty, G. H., Stanton, T. W., and Knowlton, F. H., 1899, Geology of the Yellowstone National Park; Part 2, Descriptive geology, petrography, and paleontology: U.S. Geol. Survey Mon. 32, 893 p.

Hancock, E. T., 1918, Geology and oil and gas prospects of the Lake Basin field, Montana: U.S. Geol. Survey Bull. 691–D, p. 101–147.

——— 1920, The Mule Creek oil field, Wyoming: U.S. Geol. Survey Bull. 716–C, p. 35–53.

Häntzschel, Walter, 1962, Trace fossils and Problematica *in* Moore, R. C., ed., Treatise on invertebrate paleontology—Part W, Miscellanea: New York and Lawrence, Kans., Geol. Soc. America and Univ. Kansas Press, p. W177–W259.

Hares, C. J., 1916, Anticlines of central Wyoming: U.S. Geol. Survey Bull. 641–I, p. 233–279.

——— 1917, Gastroliths in the Cloverly Formation: Wash. Acad. Sci. Jour., v. 7, p. 429.

Hatcher, J. B., and Stanton, T. W., 1903, The stratigraphic position of the Judith River beds and their correlation with the Belly River beds: Science, new ser., v. 18, no. 450, p. 211–212.

Hewett, D. F., 1914, The Shoshone River section, Wyoming: U.S. Geol. Survey Bull. 541, p. 89–113.

Hewitt, D. F., and Lupton, C. T., 1917, Anticlines in the southern part of the Bighorn basin, Wyoming: U.S. Geol. Survey Bull. 656, 192 p.

Hintze, F. F., Jr., 1915, The Basin and Greybull oil and gas fields: Wyoming Geol. Survey Bull. 10, 62 p.

Horberg, Leland, 1940, Geomorphic problems and glacial geology of the Yellowstone Valley, Park County, Montana: Jour. Geology, v. 48, p. 275–303.

Horn, G. H., 1959, Geologic and structure map of the West Salt Creek oil field, Natrona County, Wyoming: U.S. Geol. Survery open-file rept., 1 map.

Hose, R. K., 1955, Geology of the Crazy Woman Creek area, Johnson County, Wyoming: U.S. Geol. Survey Bull. 1027–B, p. 33–118.

Houston, R. S., and Murphy, J. F., 1962, Titaniferous black sandstone deposits of Wyoming: Wyoming Geol. Survey Bull. 49, 120 p.

Iddings, J. P., and Weed, W. H., 1894, Description of the Livingston sheet [Montana]: U.S. Geol. Survey Geol. Atlas, Folio 1, 5 p.

James, H. L., 1946, Chromite deposits near Red Lodge, Carbon County, Mont.: U.S. Geol. Survey Bull. 945–F, p. 151–189.

Jones, W. R., Peoples, J. W., and Howland, A. L., 1960, Igneous and tectonic structures of the Stillwater Complex, Montana: U.S. Geol. Survey Bull. 1071–H, p. 281–340.

Keefer, W. R., 1957, Geology of the DuNoir area, Fremont County, Wyoming: U.S. Geol. Survey Prof. Paper 294–E, p. 155–221.

——— 1970, Structural geology of the Wind River Basin, Wyoming: U.S. Geol. Survey Prof. Paper 495–D, 37 p.

Keefer, W. R., and Rich, E. I., 1957, Stratigraphy of the Cody Shale and younger Cretaceous and Paleocene rocks in the western and southern parts of the Wind River Basin, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 12th Ann. Field Conf., southwest Wind River Basin, Lander, Wyoming, September 1957: p. 71–78.

Keefer, W. R., and Troyer, M. L., 1964, Geology of the Shotgun Butte area, Fremont County, Wyoming: U.S. Geol. Survey Bull. 1157, 123 p.

Klepper, M. R., Weeks, R. A., and Ruppel, E. T., 1957, Geology of the southern Elkhorn Mountains, Jefferson and Broadwater Counties, Montana: U.S. Geol. Survey Prof. Paper 292, 82 p.

Knappen, R. S., and Moulton, G. F., 1931, Geology and mineral resources of parts of Carbon, Bighorn, Yellowstone, and Stillwater Counties, Montana: U.S. Geol. Survey Bull 822–A, p. 1–70.

Knechtel, M. M., and Patterson, S. H., 1956, Bentonite deposits in marine Cretaceous formations of the Hardin district, Montana and Wyoming: U.S. Geol. Survey Bull. 1023, 116 p.

——— 1962, Bentonite deposits of the northern Black Hills district, Wyoming, Montana, and South Dakota: U.S. Geol. Survey Bull. 1082–M, p. 893–1027.

Knight, W. C., 1902, The petroleum fields of Wyoming: Eng. Mining Jour., v. 73, p. 720–723.

Knowlton, F. H., 1892, The fossil flora of the Bozeman coal field: Biol. Soc. Washington Proc., v. 7, p. 153–154.

Lammers, E. C. H., 1939, The origin and correlation of the Cloverly conglomerate: Jour. Geology, v. 47, no. 2, p. 113–132.

Lee, W. T., 1927, Correlation of geologic formations between east-central Colorado, central Wyoming, and southern Montana: U.S. Geol. Survey Prof. Paper 149, 80 p.

Lesquereux, Leo, 1873, Lignitic formation and fossil flora *in* Hayden, F. V., United States geological survey of the Territories, 6th annual report, 1872: Washington, D.C., p. 317–427.

Lindgren, Waldemar, 1886, Eruptive rocks (of Montana) *in* Report on the mining industries of the United States: U.S. Census, 10th, v. 15, p. 719–737.

Love, J. D., 1948, Mesozoic stratigraphy of the Wind River Basin, central Wyoming, *in* Wyoming Geol. Assoc. Guidebook 3d Ann. Field Conf., Wind River Basin, Casper, Wyoming, 1948: p. 96–111.

——— 1956, Cretaceous and Tertiary stratigraphy of the Jackson Hole area, northwestern Wyoming, *in* Wyoming Geol. Assoc. Guidebook 11th Ann. Field Conf., Jackson Hole, Wyoming, 1956: p. 76–94.

Lupton, C. T., 1916, Oil and gas near Basin, Bighorn County, Wyoming, *in* Part 2, Mineral Fuels: U.S. Geol. Survey Bull. 621–L, p. 157–190.

Lyons, J. B., 1944, Igneous rocks of the northern Big Belt Range, Montana: Geol. Soc. America Bull., v. 55, p. 445–472.

McMannis, W. J., 1955, Geology of the Bridger Range, Montana: Geol. Soc. America Bull., v. 66, no. 11, p. 1385–1430.

——— 1963, LaHood Formation—a coarse facies of the Belt Series in southwestern Montana: Geol. Soc. America Bull., v. 74, p. 407–436.

——— 1965, Résumé of depositional and structural history of western Montana: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 11, p. 1801–1823.

McMannis, W. J., and Chadwick, R. A., 1964, Geology of the Garnet Mountain quadrangle, Gallatin County, Montana: Montana Bur. Mines and Geology Bull. 43, 47 p.

Mapel, W. J., 1959, Geology and coal resources of the Buffalo–Lake De Smet area, Johnson and Sheridan Counties, Wyoming: U.S. Geol. Survey Bull. 1078, 148 p.

Mapel, W. J., Robinson, C. S., and Theobald, P. K., 1959, Geologic and structure contour map of the northern and western flanks of the Black Hills, Wyoming, Montana, and South Dakota: U.S. Geol. Survey Oil and Gas Inv. Map OM–191, scale 1:96,000.

Moberly, Ralph, Jr., 1960, Morrison, Cloverly, and Sykes Mountain formations, northern Bighorn Basin, Wyoming and Montana: Geol. Soc. America Bull., v. 71, no. 8, p. 1137–1176.

Osterwald, F. W., 1961, Critical review of some tectonic problems in Cordilleran foreland: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 2, p. 219–237.

Parsons, W. H., 1942, Origin and structure of the Livingston igneous rocks, Montana: Geol. Soc. America Bull., v. 53, no. 8, p. 1175–1186.

Peale, A. C., 1896, Description of the Three Forks sheet [Montana]: U.S. Geol. Survey Geol. Atlas, Folio 24, 7 p., 4 maps.

Peck, R. E., 1941, Lower Cretaceous Rocky Mountain nonmarine microfossils: Jour. Paleontology, v. 15, no. 3, p. 285–304.

Pierce, W. G., 1957, Heart Mountain and South Fork detachment thrusts of Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 4, p. 591–626.

——— 1963, Cathedral Cliffs Formation, the early acid breccia unit of northwestern Wyoming: Geol. Soc. America Bull., v. 74, no. 1, p. 9–22.

Post, E. V., and Bell, Henry, 3d, 1961, Chilson Member of the Lakota Formation in the Black Hills, South Dakota and Wyoming: U.S. Geol. Survey Prof. Paper 424–D, p. D173–D178.

Prucha, J. J., Graham, J. A., and Nickelsen, R. P., 1965, Basement-controlled deformation in Wyoming province of Rocky Mountains foreland: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 7, p. 966–992.

Pumpelly, Raphael, 1886, Bituminous coals and lignites of the Northwest *in* Report on the mining industries of the United States, 1880: U.S. Census, 10th, v. 15, p. 691–695.

Reeside, J. B., Jr., 1927, The cephalopods of the Eagle sandstone and related formations in the Western Interior of the United States: U.S. Geol. Survey Prof. Paper 151, 87 p.

——— 1944, Map showing thickness and general character of the Cretaceous deposits in the Western Interior of the United States: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 10, scale 1 inch to 3 miles (1:633,600).

——— 1957, Paleoecology of the Cretaceous seas of the Western Interior of the United States, Chap. 18 *of* Ladd, H. S., ed., Paleoecology: Geol. Soc. America Mem. 67, p. 505–541.

Reeside, J. B., Jr., and Cobban, W. A., 1960, Studies of the Mowry Shale (Cretaceous) and contemporary formations in the United States and Canada: U.S. Geol. Survey Prof. Paper 355, 126 p.

Reeves, Frank, 1927, Geology of the Cat Creek and Devils Basin oil fields and adjacent areas in Montana: U.S. Geol. Survey Bull. 786–B, p. 39–95.

——— 1931, Geology of the Big Snowy Mountains, Mont.: U.S. Geol. Survey Prof. Paper 165–D, p. 135–149.

Richards, P. W., 1955, Geology of the Bighorn Canyon–Hardin area, Montana and Wyoming: U.S. Geol. Survey Bull. 1026, 93 p.

——— 1957, Geology of the area east and southeast of Livingston, Park County, Montana: U.S. Geol. Survey Bull. 1021–L, p. 385–438.

Roberts, A. E., 1957, Coal-bearing rocks and mines at Cokedale, Park County, Montana, *in* Billings Geol. Soc. Guidebook 8th Ann. Field Conf., Crazy Mountains basin, Montana, September 1957: p. 39–47.

——— 1963, The Livingston Group of south-central Montana: U.S. Geol. Survey Prof. Paper 475–B, p. B86–B92.

——— 1964a, Geology of the Brisbin quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–256.

——— 1964b, Geology of the Chimney Rock quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–257.

——— 1964c, Geology of the Hoppers quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–258.

——— 1964d, Geology of the Livingston quadrangle, Montana: U.S. Geol. Survey Geol. Quad. Map GQ-259.

——— 1964e, Geologic map of the Maxey Ridge quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I-396.

——— 1964f, Geologic map of the Fort Ellis quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I-397.

——— 1964g, Geologic map of the Mystic Lake quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I-398.

——— 1964h, Geologic map of the Bozeman Pass quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I-399.

——— 1965, Correlation of Cretaceous and lower Tertiary rocks near Livingston, Montana, with those in other areas in Montana and Wyoming: U.S. Geol. Survey Prof. Paper 525-B, p. B54-B63.

——— 1966, Geology and coal resources of the Livingston coal field, Gallatin and Park Counties, Montana: U.S. Geol. Survey Prof. Paper 526-A, 56 p.

Robinson, C. S., Mapel, W. J., and Bergendahl, M. H., 1964, Stratigraphy and structure of the northern flanks of the Black Hills uplift, Wyoming, Montana, and South Dakota: U.S. Geol. Survey Prof. Paper 404, 134 p.

Robinson, C. S., Mapel, W. J., and Cobban, W. A., 1959, Pierre Shale along western and northern flanks of Black Hills, Wyoming and Montana: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 1, p. 101-123.

Robinson, G. D., 1961, Origin and development of the Three Forks basin, Montana: Geol. Soc. America Bull., v. 72, no. 7, p. 1003-1014.

——— 1963, Geology of the Three Forks quadrangle, Montana: U.S. Geol. Survey Prof. Paper 370, 143 p.

Robinson, G. D., Klepper, M. R., and Obradovich, J. D., 1969, Overlapping plutonism, volcanism, and tectonism in the Boulder batholith region, western Montana: Geol. Soc. America Mem. 116, p. 557-576.

Robinson, G. D. and Marvin, R. F., 1967, Upper Cretaceous volcanic glass from western Montana: Geol. Soc. America Bull., v. 78, p. 601-608.

Ross, C. P., Andrews, D. A., and Witkind, I. J., 1955, Geologic map of Montana: Washington, U.S. Geol. Survey, scale 1:250,000, 2 sheets.

Rubel, D. N., 1964, Geology of the Independence area, Sweetgrass and Park Counties, Mont: Ann Arbor, Michigan Univ., Ph. D. thesis (available on microfilm from University Microfilms, Inc., Ann Arbor, Mich.).

Rubey, W. W., 1929, Origin of the siliceous Mowry Shale of the Black Hills region: U.S. Geol. Survey Prof. Paper 154-D, p. 153-170.

——— 1931, Lithologic studies of fine-grained Upper Cretaceous sedimentary rocks of the Black Hills region: U.S. Geol. Survey Prof. Paper 165-A, p. 1-54.

Schmidt, R. G., and Zubovic, Peter, 1961, Cobern Mountain overthrust, Lewis and Clark County, Montana: U.S. Geol. Survey Prof. Paper 424-C, p. C175-C177.

Seager, G. F., 1944, Gold, arsenic, and tungsten deposits of the Jardine-Crevasse Mountain district, Park County. Montana: Montana Bur. Mines and Geology Mem. 23, 111 p.

Simms, F. E., 1966, The igneous petrology, geochemistry, and structural geology of part of the northern Crazy Mountains, Montana: Cincinnati, Ohio, Univ. Cincinnati, Ph. D. thesis (available on microfilm from University Microfilms, Inc., Ann Arbor, Mich.).

Simpson, G. G., 1937, The Fort Union of the Crazy Mountain field, Montana, and its mammalian faunas: U.S. Natl. Mus. Bull. 169, 287 p.

Sims, J. D., 1967, Geology and sedimentology of the Livingston Group, northern Crazy Mountains, Montana: Evanston, Ill., Northwestern Univ., Ph. D. thesis (available on microfilm from University Microfilms, Inc., Ann Arbor, Mich.).

Skeels, D. C., 1939, Structural geology of the Trail Creek-Canyon Mountain area, Montana: Jour. Geology, v. 47, no. 8, p. 816-840.

Skipp, B. A. L., and Hepp, M. M., 1968, Geologic map of the Hatfield Mountain quadrangle, Gallatin County, Montana: U.S. Geol. Survey Geol. Quad. Map GQ-729, scale 1:24,000.

Skipp, B. A. L., and Peterson, A. D., 1965, Geologic map of the Maudlow quadrangle, southwestern Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I-452, scale 1:24,000, 2 sheets.

Slaughter, Maynard, and Earley, J. W., 1965, Mineralogy and geological significance of the Mowry bentonites, Wyoming: Geol. Soc. America Spec. Paper 83, 116 p.

Smedes, H. W., 1966, Geology and igneous petrology of the northern Elkhorn Mountains, Jefferson and Broadwater Counties, Montana: U.S. Geol. Survey Prof. Paper 510, 116 p.

Smith, J. G., 1965, Fundamental transcurrent faulting in northern Rocky Mountains: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 9, p. 1398-1409.

Stanton, T. W., 1903, A new fresh-water molluscan faunule from the Cretaceous of Montana: Am. Philos. Soc. Proc., v. 42, p. 188-199.

Stebinger, Eugene, 1914a, Titaniferous magnetite beds on the Blackfeet Indian Reservation, Montana: U.S. Geol. Survey Bull. 540-H, p. 329-337.

——— 1914b, The Montana group of northwestern Montana: U.S. Geol. Survey Prof. Paper 90, p. 61-68.

Stokes, W. L., 1942, Some field observations bearing on the origin of the Morrison gastroliths: Science, v. 95, no. 2453, p. 18-19.

Stoll, W. C., and Armstrong, F. C., 1958, Optical calcite deposits in Park and Sweetgrass Counties, Montana: U.S. Geol. Survey Bull. 1042-M, p. 431-479.

Stone, R. W., 1908, Coal near the Crazy Mountains, Montana, *in* Part 2, Coal and lignite: U.S. Geol. Survey Bull. 341, p. 78-91.

Stone, R. W., and Calvert, W. R., 1910, Stratigraphic relations of the Livingston Formation of Montana: Econ. Geology, v. 5, no. 6, p. 551-557; no. 7, p. 652-669; and no. 8, p. 741-764.

Stow, M. H., 1938, Dating Cretaceous-Eocene tectonic movements in Bighorn Basin by heavy minerals: Geol. Soc. America Bull., v. 49 p. 731-761.

——— 1946, Dating sedimentation, vulcanism and orogeny in Beartooth Mountain region, Montana, by heavy minerals: Geol. Soc. America Bull., v. 57, p. 675-686.

Tanner, J. J., 1949, Geology of the Castle Mountain area, Montana: Princeton, N.J., Princeton Univ., Ph. D. thesis (available on microfilm from University Microfilms, Inc., Ann Arbor, Mich.).

Tappe, John, 1966, The chemistry, petrology, and structure of the Big Timber igneous complex, Crazy Mountains, Montana: Cincinnati, Ohio, Univ. Cincinnati, Ph. D. thesis (available on microfilm from University Microfilms, Inc., Ann Arbor, Mich.).

Thom, W. T., Jr., 1922, Oil and gas prospects in and near the Crow Indian Reservation, Montana: U.S. Geol. Survey Bull. 736-B, p. 35-53.

Thom, W. T., Jr., Hall, G. M., Wegemann, C. H., and Moulton, G. F., 1935, Geology of Big Horn County and the Crow Indian Reservation, Montana: U.S. Geol. Survey Bull, 856, 200 p.

Thompson, R. M., Love, J. D., and Tourtelot, H. A., 1949, Stratigraphic sections of pre-Cody Upper Cretaceous rocks in central Wyoming: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart 36, vertical scale, 1 inch to 200 feet (1:2,400), 2 sheets.

Tilling, R. I., Klepper, M. R., and Obradovich, J. D., 1968, K-Ar ages and time span of emplacement of the Boulder batholith Montana: Am. Jour. Sci., v. 266, p. 671–689.

Tschudy, R. H., and Veach, S. D., 1965, Plant and miscellaneous microfossils from the Thermopolis and Mowry Shales: U.S. Geol. Survey open-file rept., 6 p.

Van Houten, F. B., 1962, Frontier Formation, Bighorn Basin, Wyoming, *in* Symposium on Early Cretaceous rocks of Wyomining and adjacent areas, Wyoming Geol. Assoc., 17th annual field conference, 1962: Casper, Wyo., Petroleum Information, p. 221–231.

Vhay, J. S., 1934, The geology of a part of the Beartooth Mountain front near Nye, Montana: Princeton, N.J., Princeton Univ., Ph. D. thesis (aivailable on microfilm from University Microfilms, Inc., Ann Arbor, Mich.).

——— 1939, Some features of the Livingston Formation near Nye, Montana: Am. Geophys. Union Trans., 20th Ann. Mtg., pt. 3, p. 433–437.

Viele, G. W., and Harris, F. G., 3d, 1965, Montana Group stratigraphy, Lewis and Clark County, Montana: Am. Assoc., Petroleum Geologists Bull., v. 49, p. 379–417.

Waagé, K. M., 1955, Dakota Group in northern Front Range foothills, Colorado: U.S. Geol. Survey Prof. Paper 274–B, p. 15–51.

——— 1959, Stratigraphy of the Inyan Kara Group in the Black Hills: U.S. Geol. Survey Bull. 1081–B, p. 11–90.

Washburne, C. W., 1908, Gas fields of the Bighorn Basin, Wyoming: U.S. Geol. Survey Bull. 340–F, p. 348–363.

Weed, W. H., 1893, The Laramie and the overlying Livingston Formation in Montana: U.S. Geol. Survey Bull. 105, 68 p.

——— 1899a, Description of the Fort Benton quadrangle, [Montana]: U.S. Geol. Survey Geol. Atlas, Folio 55, 9 p.

——— 1899b, description of the Little Belt Mountains quadrangle, [Montana]: U.S. Geol. Survey Geol. Atlas, Folio 56, 11 p.

Weimer, R. J., and Hoyt, J. H., 1964, Burrows of *Callianassa major* Say, geologic indicators of littoral and shallow neritic environments: Jour. Paleontology, v. 38, No. 4, p. 761–767.

Wentworth, C. K., and Williams Howel, 1932, The classification and terminology of the pyroclastic rocks: Natl. Research Council Bull. 89, p. 19–53.

Williams, Howel, Turner, F. J., and Gilbert, C. M., 1954, Petrography—An introduction to the study of rocks in thin sections: San Francisco, W. H. Freeman and Co., 406 p.

Wilson, C. W., Jr., 1934, Geology of the thrust fault near Gardiner, Montana: Jour. Geology, v. 42, no. 6, 649–663.

——— 1936, Geology of the Nye-Bowler lineament, Stillwater and Carbon Counties, Montana: Am. Assoc. Petroleum Geologists Bull., v. 20, no. 9, p. 1161–1188.

Wolff, J. E., 1938, Igneous rocks of the Crazy Mountains, Montana: Geol. Soc. America Bull., v. 49, p. 1569–1626.

Wood, H. E., 2d, chm., and others, 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., v. 52, no. 1, p. 1–48.

Yen, T. C., 1951, Fresh-water mollusks of Cretaceous age from Montana and Wyoming: U.S. Geol. Survey Prof. Paper 233–A pt. 1, p. 1–9.

Young, Keith, 1951, Foraminifera and stratigraphy of the Frontier Formation (Upper Cretaceous), southern Montana: Jour. Paleontology, v. 25, no. 1, p. 35–68.

Zapp, A. D., and Cobban, W. A., 1960, Some late Cretaceous strand lines in northwestern Colorado and northeastern Utah: U.S. Geol. Survey Prof. Paper 400–B, p. B246–B249.

INDEX

[Italic page numbers indicate major references]

Geological-Geophysical Investigations of Bedrock in the Island Falls Quadrangle, Aroostook and Penobscot Counties, Maine

GEOLOGICAL SURVEY PROFESSIONAL PAPER 527

Geological-Geophysical Investigations of Bedrock in the Island Falls Quadrangle, Aroostook and Penobscot Counties, Maine

By E. B. EKREN *and* F. C. FRISCHKNECHT

GEOLOGICAL SURVEY PROFESSIONAL PAPER 527

Description of the stratigraphy and structure of lower Paleozoic rocks in the Island Falls quadrangle and the results of using geophysical techniques to trace certain strata beneath covered areas

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1967

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. GS 67-152

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

TABLES

GEOLOGICAL-GEOPHYSICAL INVESTIGATIONS OF BEDROCK IN THE ISLAND FALLS QUADRANGLE, AROOSTOOK AND PENOBSCOT COUNTIES, MAINE

By E. B. Ekren and F. C. Frischknecht

ABSTRACT

The geology of the Island Falls quadrangle was studied by means of electromagnetic and magnetic surveys in conjunction with conventional geologic mapping techniques.

Bedrock in the quadrangle ranges in age from Cambrian(?) to Devonian and consists dominantly of graywacke and slate. The oldest strata are part of the Grand Pitch Formation of Cambrian(?) age. The Grand Pitch Formation crops out in the northern part of the quadrangle; it consists of black to medium-gray slate (some of which is conductive) and finely laminated gray siltstone and quartzite. Quartzite and quartz-rich grit form only about a fourth of the volume but are a conspicuous part of the formation. The Grand Pitch is unconformably overlain by conglomerate, tuffaceous sandstone, and ash-fall tuff of the Shin Brook Formation of Early or early Middle Ordovician age. The Shin Brook Formation is generally confined to troughs of synclines in and around Green Mountain. Northwest of Green Mountain the formation is absent, and the Grand Pitch is overlain by Silurian strata. To the southeast, on the other hand, the Grand Pitch is overlain by or is in fault contact with thick spilite and keratophyre lava flows of Ordovician age that may be contemporaneous in part with the tuffaceous strata of the Shin Brook. The lavas form a rugged topographic ridge that extends across the quadrangle from Mount Chase northeast to Shoaler Mountain. The lava pile is about 12,000 feet thick at Mount Chase and about 3,000 feet thick at Shoaler Mountain. Numerous sills of medium-grained spilite or albite diabase occur within the extrusive strata along the Mount Chase ridge. These are presumably genetically related to the lavas.

The southeastern half of the quadrangle is underlain by a thick monotonous sequence of cyclically bedded conglomeratic graywacke, graywacke, varicolored slate, and thin-bedded limestone and siltstone. These strata have been divided into the herein-named Mattawamkeag Formation of Silurian or Ordovician age, the Allsbury Formation of Early Silurian age, and the rocks of Island Falls of Silurian age. Thick beds of conglomerate crop out just east of Patten along the Aroostook County line, at Crystal Lake, and at Bear Brook. The conglomerate contains cobbles and boulders of greenstone and quartz diorite that are believed to be locally derived. The conglomerate probably correlates with conglomeratic strata in the Stacyville quadrangle that contain fragments of Silurian brachiopods.

Two stocks of quartz diorite measuring 8 miles by 3 miles and 2 miles by about 1 mile, respectively, are present in the north-central part. The quartz diorite, named herein the Rockabema Quartz Diorite, intrudes strata of the Grand Pitch and Shin Brook Formations and the spilite lavas; it is intensely sheared and brecciated. Boulders of quartz diorite that are petrographically very similar to the rock in the stocks are found in the conglomerate beds that crop out east of Patten and at Bear Brook. The stocks are therefore considered to be younger than early Middle Ordovician and older than Silurian in age.

A small elongate stock of coarse-grained granite less than a mile long occurs along the east border of the quadrangle near De Lette Ridge, and the western margin of a large stock of granodiorite and quartz monzonite is present along the east border just east of the town of Island Falls. The intrusive rock in both stocks is fresh and unaltered, and postdates the major structural deformation of the Island Falls area. Potassium-argon age determinations of rock from the larger stock indicate a late Early or Middle Devonian age.

With the exception of the granitic rocks along the east border all the rocks in the quadrangle have been intensely deformed. Dips of less than 70° in bedded strata are uncommon, and cleavage is well developed throughout. The mineral assemblage indicates that the Island Falls area is in the chlorite zone of regional metamorphism.

Electromagnetic surveys employing the slingram method delimited and traced many zones of conductive black slate in the Allsbury and Grand Pitch Formations. Commonly a series of conductors occur together in a zone which may be several hundred feet wide, although isolated conductors representing single beds 20–30 feet wide are common. In the Allsbury Formation, narrow belts of conductors were traced as far as 10 miles. The delineation of these black slate zones was an invaluable aid in correlating strata from outcrop to outcrop, and also in determining the strike and extent of large folds.

Electromagnetic results from surveys of the Grand Pitch Formation were more complex than those from the Allsbury Formation, and individual anomalies seldom could be correlated between widely spaced traverses. Apparently there is considerable local folding in the black slates which does not parallel the regional strike, or else faults are present that could not be discerned in the field. Several belts containing many individual beds of conductive black slate were outlined; in many localities the buried contact between the Grand Pitch Formation and younger rocks was located by electromagnetic traverses.

The published aeromagnetic map of the quadrangle provided a valuable framework for the geologic studies. The volcanic rocks, the Allsbury Formation, and the baked rocks surrounding the granite stocks in the eastern part of the quadrangle are most magnetic. Ground magnetic surveys indicate that the anomalies in the Allsbury Formation result chiefly from black slate, which is often conductive as well as magnetic.

INTRODUCTION

PURPOSE AND SCOPE

Large areas of Maine are underlain by thick sequences of graywacke and slate. These rocks are not resistant to erosion and are very poorly exposed through the blanket of glacial drift. It is almost impossible to project contacts accurately in these areas, and geologists have long felt the need of a geophysical means of mapping contacts from one isolated outcrop to another. For this purpose, several methods may be used. In the iron range country of the United States, ground magnetic and, to a lesser extent, electromagnetic surveys are used to trace iron formations and other magnetic or conductive units. In parts of Canada adjacent to Maine, electromagnetic surveys made in a search for ore have provided very valuable geologic information of a more general nature by outlining large belts of conductive carbonaceous or graphitic slates. Reconnaissance electromagnetic surveying in several quadrangles in northern and eastern Maine during the summers of 1957 and 1958 (Frischknecht and Ekren, 1960) revealed that many black slates there are conductors. Traverses in the southeast corner of the Shin Pond quadrangle just west of the Island Falls quadrangle indicated the presence of several northeast-striking conductors in gently rolling terrain where the bedrock was almost completely covered by glacial drift. Reconnaissance geologic mapping by R. B. Neuman (oral commun., 1958) suggested that the strata containing the conductors in the Shin Pond quadrangle occur also in the Island Falls quadrangle and there constitute the bulk of the bedrock in the southeastern half of the quadrangle. To determine the extent of this conductive bedrock and to evaluate ground electromagnetic surveys supplemented by magnetic surveys as a possible major aid to geologic mapping, a study of the geology of the Island Falls quadrangle was undertaken. The two geophysical methods as well as conventional geologic mapping techniques were employed in the study, which was begun in July 1959 and completed in October 1961.

In this report Ekren wrote the descriptions of stratigraphy and structure, and Frischknecht wrote the section on geophysical investigations. The authors are jointly responsible for the interpretation of structure and the correlation of units based on the results of the geophysical surveys.

GEOGRAPHY

The Island Falls quadrangle lies in northeastern Maine (fig. 1) astride the Penobscot-Aroostook County line, south of the main potato-producing country of northern Maine and east of Baxter State Park, the heart of Maine's wilderness area. The West Branch Mattawamkeag River is the principal stream; it is navigable by canoe from State Highway 11 in the north-central part of the quadrangle to the town of Island Falls in the extreme southeastern part. Patten and Island Falls are the only towns, both served by the Bangor and Aroostook Railroad. Lumbering, mainly for pulp, is the principal industry.

Elevations range from about 450 feet in the southeast corner to 2,440 feet at the summit of Mount Chase in the west-central part. A prominent ridge extends northeastward from Mount Chase across the quadrangle and divides the quadrangle into two distinctly

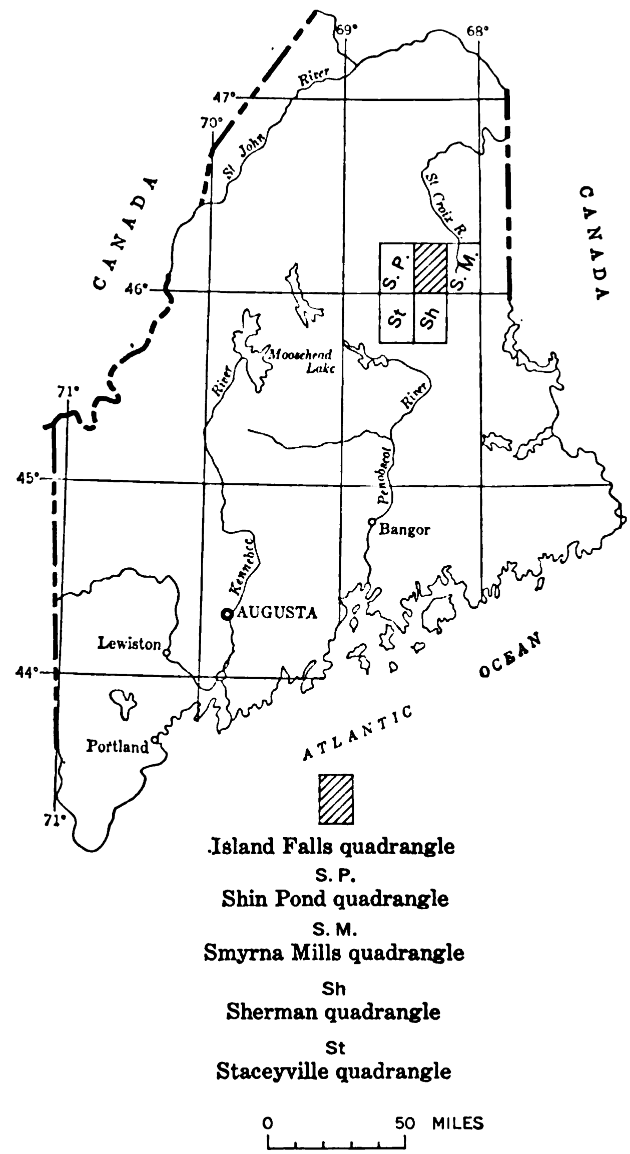


FIGURE 1.—Location of Island Falls and adjacent quadrangles referred to in this report.

different parts. To the northwest the land is rugged and covered with forest; to the southeast the land is gently rolling, and much of it has been cleared. Roads and trails are abundant in the southeastern part but scarce in the northwestern part.

Bedrock is exposed in approximately 5–10 percent of the area, mainly in streambeds and on the rugged ridge that extends from Mount Chase to Shoaler Mountain. The remainder of the area is covered with glacial drift that varies in thickness from a few feet to slightly more than 150 feet. The drift is thinnest in the southeastern part and thickest near Pleasant Lake, where preglaciation streams had cut a broad valley. Two wells just west of Pleasant Lake at Shin Pond in the Shin Pond quadrangle produce water from glacial drift at depths of about 160 feet.

ACKNOWLEDGMENTS

Robert B. Neuman of the U.S. Geological Survey had nearly completed the mapping of the adjacent Shin Pond quadrangle prior to the start of the Island Falls study. During his mapping, Neuman made several geologic traverses in the Island Falls quadrangle and had partly delineated the general structure and stratigraphy. The results of his reconnaissance work, made available to the authors, greatly facilitated the present study. Mr. Neuman also offered many constructive suggestions and ideas during the course of the study and the preparation of this manuscript. Louis Pavlides, mapping in the adjacent Smyrna Mills quadrangle, spent several days in the field with the authors, acquainting them with some of the stratigraphic units common to both quadrangles.

During the summer of 1959, A. S. Barwick was a geologic field assistant, and in 1960 he mapped independently in the field. Dallas Jackson served as geologic field assistant in 1961. Keith McElroy of Patten, Maine, was employed all three summers as surveying assistant and brush cutter. His intimate knowledge of the area, ability to handle a canoe, and cheerful spirit contributed greatly to fieldwork efficiency.

STRATIGRAPHY

CAMBRIAN(?) SYSTEM

GRAND PITCH FORMATION

The oldest rocks exposed in the quadrangle are part of the Grand Pitch Formation (Neuman, 1962, p. 794), formerly the Grand Falls Formation of Ruedemann and Smith (1935, p. 354). The type locality of the formation is the Grand Pitch of the East Branch Penobscot River a few miles west of the Island Falls quadrangle.

The Grand Pitch Formation underlies a broad area in the northern part of the quadrangle (pl. 1) but is poorly exposed. It consists of thin- and thick-bedded gray and dark-gray quartzite, coarse quartzitic grit, and conglomeratic quartzite interbedded with black to gray and, less commonly, green and green-gray thin-bedded slate and siltstone. The formation was mapped as two units, on the basis of the occurrence of conductive strata. The conductive zones consist mostly of black slate but include minor amounts of thin-bedded quartzite and siltstone. The nonconductive zones contain relatively more quartzite and siltstone and less slate, which is dominantly gray or green gray.

QUARTZITE

About a fourth of the Grand Pitch Formation in the quadrangle is made up of quartzite, quartzitic grit, and sparse conglomeratic quartzite and quartz graywacke. The rocks, though very hard, are highly fractured and interbedded with slate; therefore, they are not resistant to erosion. Areas underlain by beds of quartzite are commonly marked by abundant angular quartzite boulders intermixed with glacial debris.

The quartzite occurs in even beds a few inches to several feet thick. Although the Grand Pitch as a whole is well stratified, stratification is generally obscure within single beds, and this is true for most of the quartzite. In places, however, quartzite that grades to siltstone and slate is finely cross laminated. The laminae are commonly varicolored in shades of gray, black, and white. A distinctive feature in outcrops of both fine-grained quartzite and coarse grit is the abundance of veinlets of white quartz, which rarely exceed an inch in thickness and average considerably less. The veinlets are anastomosing and in places form stockworks.

The quartzite (fig. 2) contains, on the average, more than 80 percent quartz. Accessory minerals include plagioclase, zircon, garnet, tourmaline, and leucoxene. Magnetite, pyrite, and carbon are locally abundant. The magnetite is dominantly secondary, occurring as tiny euhedral octahedrons. The rock contains chlorite that is pseudomorphically derived from biotite.

Modes of two quartzites and a quartz graywacke are shown in table 1.

SLATE

Slate in the Grand Pitch Formation is characterized by sharply curved cleavage planes caused by cross folding that deformed an earlier cleavage. The slate might best be termed curly slate; upon weathering it breaks into splinters and small curved fragments. Occurrence of such characteristic splinters can be used to distinguish the Grand Pitch Formation from younger rocks in areas of poor exposure or complex structure.

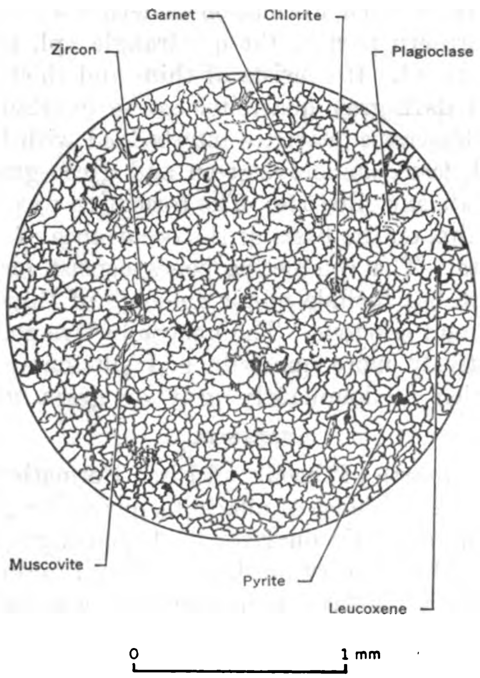


FIGURE 2.—Light-greenish-gray quartzite from the Grand Pitch Formation. The rock is a mosaic of very fine grained quartz containing sparse accessory minerals, sericite, and chlorite. Contacts between grains of quartz are outlined in part by tiny shreds of sericite. The opaque grains are crystals of leucoxene that are yellowish white in reflected light. A single cube of pyrite is in lower right. Sample 59–B7, from new tote road to Rockabema Lake.

TABLE 1.—*Modes of two quartzites and a quartz graywacke*

	59B7	59IF8-3-1	60IF8-15-2
Quartz	83.6	81.4	65.6
Matrix	----	----	[1] 26.4
Potassium feldspar	Tr.	1.2	1.2
Plagioclase	6.4	8.8	3.6
Chlorite (includes green biotite)	.8	4.8	----
Chert	Tr.	1.2	1.2
Sericite	8.0	1.0	----
Magnetite	.8	.4	.4
Pyrite	.4	.6	Tr.
Calcite	----	.6	----
Zircon	Tr.	Tr.	.4
Tourmaline	Tr.	Tr.	Tr.
Limonite	----	----	1.2
Garnet	Tr.	Tr.	----
Total	100.0	100.0	100.0

[1] Matrix is mostly sericite with small amounts of chlorite and quartz and sparse carbon.

59B7. Light-greenish-gray quartzite exposed on old tote road about 0.5 mile west o intersection with State Highway 11 about 1.2 miles south of Knowles Corner
59IF8-3-1. Black quartzite exposed below log bridge at West Hastings Brook and Lane Brook tote road.
60IF8-15-2. Dark-green-gray quartz graywacke, from east bank of Green Mountain Pond.

Thin sections of two dark conductive slates indicate that they are quartz-sericite slates containing abundant carbon in the form of fine dust, tiny blebs, and thin films. Common accessory minerals are pyrite, magnetite, leucoxene, and zircon. Tiny needles of rutile are abundant in a highly conductive slate from the northernmost conductive belt in T. 7 N., R. 5 W. The X-ray analysis (Theodore Botinelly, written commun., 1960) indicates that the carbon in the slate is not graphite. The conductivity of the slate is apparently determined by the abundance of carbon and the arrangement of the carbon particles in the rock. From the outcrop it is not possible to distinguish the conductive from the nonconductive slate. In general, conductive slate is black or nearly black, whereas nonconductive slate is gray or green gray. Some black slates, however, were found to be nonconductive. This absence of conductivity may be due to discontinuity of the carbon blebs and films in these slates and, therefore, the absence of continuous paths for the electrical current.

STRATIGRAPHIC RELATIONS AND AGE

The Grand Pitch is angularly overlain by fossiliferous strata of Silurian age in the vicinity of Lane Brook in the northwestern part of the quadrangle; by fossiliferous volcanic strata of the Shin Brook Formation of Early or early Middle Ordovician age in the vicinity of Green Mountain and Townline Brook; and by volcanic rocks of the Mount Chase area of probable early Middle Ordovician age in the vicinity of Rockabema Lake.

The trace fossil *Oldhamia smithi* Ruedemann has been found in several places in the Shin Pond quadrangle (Neuman, 1962, p. 795–796). No other fossils have been found in the formation. Smith (1928) concluded from the occurrence of *Oldhamia* that the beds are of Cambrian age. Neuman (1962, p. 795–796), however, pointed out:

> Several problems attend the use of *Oldhamia* as an index of Cambrian age. Objects classed under this name vary greatly in pattern; although most of these seem likely to be of organic origin, the nature of the organism that made them remains obscure. Ruedemann's (1942, p. 9) interpretation that they are the intrastratal feeding tracks of worms comparable to *Chondrites* is tenable. Previous descriptions have failed to note that the trails are raised ridges on the upper surfaces of bedding planes (or grooves on lower surfaces), a fact consistent with the feeding track interpretation.

Neuman (1962, p. 796) concluded that the Grand Pitch Formation is of Cambrian (?) age.

The complex structure of the Grand Pitch and the lack of a basal exposure precluded an accurate determination of its total thickness, which is undoubtedly several thousand feet.

ORDOVICIAN SYSTEM

SHIN BROOK FORMATION

The Shin Brook Formation (Neuman, 1964, p. E4) was named from exposures at Shin Brook in the Shin

Pond quadrangle. At the type locality the formation consists of crystal tuff, volcanic conglomerate, and fossiliferous calcareous sandstone; there, it is about 1,000 feet thick.

In the Island Falls quadrangle the formation is very similar and includes a lenticular basal conglomerate, ash-fall tuff, conglomeratic tuffaceous sandstone, and sheared felsite or light-colored slate.

The basal conglomerate crops out in several places northeast of Pleasant Lake, and in those places it overlies quartzite and black slate of the Grand Pitch Formation. The conglomerate is highly lenticular and ranges in thickness from 0 to slightly over 100 feet. In most places the rock consists of pebbles of felsite, quartzite, and slate ½–2 inches in diameter in a chlorite-rich sandstone matrix. The pebbles of quartzite and slate are clearly derived from the underlying Grand Pitch. Locally, the conglomerate contains boulder-size fragments of diverse volcanic rocks and quartzite. The conglomerate shows well-defined cleavage, and the softer pebbles and boulders have been slightly elongated and stretched parallel to cleavage planes. Bedding is generally poorly defined; where visible, it is even and shows fair grading.

The conglomerate is overlain by pale tan or green-gray sheared slaty felsite in which visible grains are absent or rare, or by coarse calcareous tuffaceous sandstone and ash-fall tuff. In thin section the felsite or slate consists of sericite and very fine grained quartz; the sandstone and ash-fall tuff consist of abundant crystals of feldspar and granules of felsite in a matrix of quartz, chlorite, sericite, and calcite. The calcareous sandstone and tuff are evenly bedded and locally show good grading. Where no conglomerate is present the base of the Shin Brook is marked by felsite, by light-colored slate, or by tuffaceous sandstone.

The Shin Brook Formation in the vicinity of Green Mountain and Townline Brook is characterized by lenticular beds of conglomerate and thick beds of calcareous tuffaceous sandstone, some of which are fossiliferous. The formation was not recognized along the northwest flank of the Mount Chase ridge, where lavas are in depositional or fault contact with the Grand Pitch. The volcanic strata there contain neither conglomerate nor fossiliferous beds of tuffaceous sandstone; however, the possibility exists that some of the strata at Mount Chase are of Shin Brook age.

Fossils were found in two localities (3 and 4, pl. 1) in tuffaceous sandstone. The following forms were identified by R. B. Neuman (1964, p. E10):

Sample locality 4 (locality *G* of Neuman, 1964):
Platytoechia boucoti Neuman, 1964
Cystoid remains

Sample locality 3 (locality *H* of Neuman, 1964):
Orthambonites robustus Neuman, 1964
Platytoechia boucoti Neuman, 1964
Cystoid remains

These brachiopods are among those found by Neuman in the Shin Pond quadrangle at Sugarloaf Mountain and Crommett Brook. He and Harry B. Whittington (Neuman, 1964, p. E23–E24, E33–E34) concluded that the fossils of the Shin Brook Formation indicate an Early or early Middle Ordovician age.

The Shin Brook Formation in the Island Falls quadrangle ranges in thickness from 0 to about 1,000 feet,

VOLCANIC ROCKS AND SLATE OF THE MOUNT CHASE AREA

Rocks under this heading include a variety of lavas, intrusive sills, slate, and pyroclastic rocks on Mount Chase. Fine-grained diabase and intrusive diabase sills in the Lane Brook Hills and Green Mountain, though not contiguous, are considered to be correlative with lithologically similar rocks on Mount Chase and are included in the description. The sills were probably intruded during the same period of volcanic activity that gave rise to the thick pile of lavas on Mount Chase.

SPILITE

Most of the rock exposed in the vicinity of Mount Chase is dark-green ophitic spilite.[1] Two types are recognized. One type is very fine grained and vesicular or amygdaloidal and commonly shows pillows. The other type is fine to medium grained, massive weathering, and nonvesicular. It forms sills throughout the quadrangle. The latter type was described separately in an earlier report (Ekren, 1961, p. D45) as albite diabase.

Thin sections indicate the spilite contains about 45 percent plagioclase, 20–45 percent augite (partly altered to chlorite, actinolite, and epidote), 2–10 percent titaniferous magnetite, and varying amounts of calcite, sphene, and pyrite. The degree of alteration varies considerably. In some thin sections, augite is fresh and clear, altered only along crystal edges and fractures to actinolite and chlorite; plagioclase (albite[2] or oligoclase) may be water clear, or it may be cloudy and contain a few crystals of epidote and fine-grained chlorite and sericite. In other thin sections both augite and plagioclase are extensively altered. Grain

[1] The term "spilite" is used herein without a genetic connotation. It denotes a nonschistose basalt or diabase whose feldspar is albite or oligoclase. The possibility that the sodic feldspar originated by Na_2O metasomatism rather than dynamometamorphism is discussed on page 21.

[2] Plagioclase compositions in most rocks were determined by comparing indices of refraction with balsam, measuring extinction angles, and determining optic sign. A few rocks were ground up, and plagioclase indices were determined by means of index oils.

size varies from less than 0.1 mm in vesicular rocks to more than 5.0 mm in a few thick massive-weathering sills. Most amygdules in the vesicular rocks contain only calcite, but a few contain intergrown quartz, epidote, chlorite, and calcite. In all thin sections the principal ore mineral appears to be titaniferous magnetite that shows octahedral parting and is extensively altered to leucoxene-coated sphene.

META-ANDESITE

Meta-andesite crops out in several places along the ridge extending from Mount Chase to Shoaler Mountain. In hand specimen the rock closely resembles very fine grained spilite; it is medium green to dark green gray, very fine grained, and slightly porphyritic, containing no more than about 5 percent phenocrysts. In thin section the rock has a felty or pilotaxitic groundmass containing abundant microlites of plagioclase. The phenocrysts are plagioclase (albite and rare remnants of oligoclase or andesine) and augite, and are as much as 2 mm in length. Quartz occurs as tiny grains in the groundmass and fills interstices between microlites of plagioclase. Other groundmass constituents are sphene, chlorite, actinolite, epidote, sericite, and a few crystals of augite and pyrite. The rock contains a small amount of sericitized potassium feldspar and as much as 15 percent more total feldspar than is average for spilite.

Meta-andesite is probably less abundant than spilite, but because the two rocks are so similar megascopically, much meta-andesite may have been overlooked during mapping. The meta-andesite may be a considerable part of the total volume of volcanic rocks in the Island Falls quadrangle.

KERATOPHYRE

Rocks called keratophyres differ principally from the meta-andesite in having more albite, more abundant phenocrysts, and fewer mafic minerals. In the Mount Chase area, the rocks are blue, blue gray, green, and green gray. Very few are amygdaloidal.

The only phenocryst in much of the keratophyre is cloudy albite, which shows mottled extinction and contains abundant secondary epidote or calcite. Some rocks contain relatively unaltered augite phenocrysts, and a few uncommon rocks contain small amounts of orthoclase. The phenocrysts average less than 3 mm in length, few exceed 5 mm; they make up 5–30 percent of the rock. Most of the rocks examined in thin section have felty or trachytic groundmasses containing abundant microlites of albite and tiny crystals of epidote or clinozoisite, chlorite, actinolite, calcite, and sphene. Magnetite is locally abundant as discrete grains and tiny veinlets. In one rock, magnetite has replaced parts of groundmass crystals and also phenocrysts of albite (Ekren, 1961, p. D44). A few rocks have finely granular groundmasses that were probably originally glassy.

Orthoclase-bearing keratophyre is not distinguishable from other keratophyres in the field, and in thin section the orthoclase phenocrysts have a peculiar patchy extinction caused by irregular patches of albite. Quartz is widespread, and some rocks are quartz keratophyre. The quartz occurs as tiny grains in the groundmass, as anhedral masses as much as 5 mm in diameter, and as veinlets.

Very few of the keratophyres are amygdaloidal; however, a keratophyre that crops out in the vicinity of Bear Mountain on the old tote road to Pleasant Lake contains so many large amygdules that in hand specimen it resembles a conglomerate. The centers of the amygdules are filled with quartz, which is surrounded by epidote and chlorite. The rock has a glomeroporphyritic texture; albite phenocrysts in clusters as much as 5 mm in diameter and augite up to 1.5 mm in diameter are set in a dense trachytic groundmass. The groundmass consists of microlites and tiny tabular crystals of albite, chlorite, actinolite, and sphene. An epidote-rich keratophyre with albite phenocrysts crops out on a steep knoll north of Mattawamkeag Hill. Quartz occurs as sparse phenocrysts and as a principal constituent in the groundmass. The groundmass quartz is micrographically intergrown with plagioclase. Staining tests indicate there is no potassium feldspar in the rock.

The abundance of secondary calcite and epidote in the plagioclase phenocrysts in these rocks, together with the mottled extinction of the albite, is clear indication that the albite is not a primary constituent. The keratophyres were probably produced by the alteration of dacitic and rhyodacitic lavas. Modes and chemical analyses of four samples of spilite, meta-andesite, and keratophyre are listed in table 2.

QUARTZ DIABASE AND QUARTZ-HORNBLENDE DIABASE

Quartz-bearing diabase and quartz-hornblende diabase crop out in three of the volcanic belts in the Island Falls quadrangle — at Green Mountain, at Knowles Corner, and southwest of Pickett Mountain Pond. The rocks in all three localities are adjacent to intrusive masses of Rockabema Quartz Diorite.

The rocks are dark green to medium green and medium grained; except for quartz and hornblende, in outcrop they appear identical with the intrusive spilite.

A thin section of quartz-bearing diabase from Green Mountain shows virtually no plagioclase. Pseudo-

TABLE 2.—*Modes and chemical analyses of four volcanic rocks from the Mount Chase area*

	Spilite	Meta-andesite	Keratophyre	
Field No.	59-E-25	60IF-9-6-2	60-8-31-5	60-6-22-5
Modes				
Quartz	0.0	Tr.	9.6	4.0
Plagioclase	50.0 An_{65}	65.0 An_{10-30}	73.8 An_{10}(?)	65.6 An_{05}
Augite	19.4	6.0		
Epidote or zoisite	.6	4.5	14.4	7.2
Actinolite	11.0	5.5		4.4
Chlorite	12.4	10.0	1.6	12.8
Sericite		4.4		
Calcite		2.2		
Sphene	.6	2.4	.6	2.0
Pyrite		Tr.		
Magnetite	6.0			
Total	100.0	100.0	100.0	100.0
Chemical analyses [Analyst, P. M. Buschman]				
Lab. No.	H3277	H3280	H3279	H3278
SiO_2	51.67	58.55	74.11	63.14
Al_2O_3	13.84	15.24	13.03	14.59
Fe_2O_3	3.39	1.60	1.26	1.89
FeO	9.64	4.72	1.80	5.56
MgO	5.19	4.70	.56	2.16
CaO	5.66	4.51	2.59	2.54
Na_2O	5.50	4.57	5.31	6.12
K_2O	.15	2.16	.04	.05
H_2O+	2.22	2.09	.64	1.95
H_2O-	.09	.14	.01	.07
TiO_2	1.89	.70	.20	.91
P_2O_5	.15	.08	.03	.28
MnO	.28	.17	.07	.16
CO_2	.02	.25	.01	.09
Cl	.00	.01	.00	.01
F	.03	.02	.01	.05
S	.03	.09	.00	.10
Total	99.75	99.60	99.67	99.67
Less O	.02	.06	.00	.07
	99.73	99.54	99.67	99.60

59-E-25. From a sill that weathers to a massive outcrop on the north slope of Mattawamkeag Hill on the west side of State Highway 11 (Aroostook Scenic Highway).
60IF-9-6-2. From the junction of the McManus tote road and the Mount Chase townline, about 2 miles northeast of Mount Chase.
60-8-31-5. From a newly blasted area on the new road to Rockabema Lake, about 250 feet west of the junction with State Highway 11, and 5,500 feet south of Knowles Corner.
60-6-22-5. From a location 4,000 feet southwest of the west shore of Pickett Mountain Pond, and 2,000 feet northeast of elevation 1370 on the north slope of the Mount Chase ridge.

morphs that appear to be after original laths and tabular crystals of plagioclase are filled with quartz, epidote, chlorite, and sparse albite. Original pyroxene has altered almost completely to chlorite, actinolite(?), and epidote. The rock contains as much as 20 percent quartz and 10 percent titaniferous magnetite. Another thin section from the same outcrop on Green Mountain contains 33 percent clear augite, 20 percent chlorite, and 37 percent plagioclase that is altered almost entirely to white, nearly opaque clay. Plagioclase remnants in this rock are calcic labradorite in composition. The rock contains about 7 percent quartz, possibly derived from the alteration or decomposition of plagioclase. Other constituents are epidote and leucoxene-coated sphene.

The rock in the vicinity of Knowles Corner contains abundant pale-green hornblende as well as quartz; it is a diorite. It is commonly a breccia that contains boulder-sized fragments of medium- to coarse-grained rock in a fine-grained matrix. In places the rock has been intruded by thin stringers of light-gray and green-gray Rockabema Quartz Diorite. Two thin sections of breccia from outcrops about half a mile apart are very similar. They contain as much as 26 percent quartz, which is partly interstitial and very fine grained and partly in the form of large crystals as much as 3 mm in diameter. The plagioclase is intensely altered, containing much clay, epidote, and sericite. Other principal minerals are unaltered pale-green hornblende and chlorite. The paragenetic sequence appears to be plagioclase followed by either hornblende or quartz. In one thin section, crystals of hornblende are poikilitic and enclose altered crystals of plagioclase and quartz. In the other thin section, however, quartz crystals commonly enclose crystals of hornblende. One rock contains several crystals of garnet, and both rocks examined in thin section contain abundant magnetite or ilmenite.

The rock exposed southwest of Pickett Mountain Pond contains 59 percent albite, 5 percent quartz, 28 percent hornblende, 5 percent epidote, 3 percent chlorite, magnetite, sericite, and apatite.

The quartz and hornblende in the diabase were probably formed by thermal metamorphism related to the intrusion of the Rockabema Quartz Diorite. The facts that support this conclusion are (1) the texture is intergranular or ophitic except that the ferromagnesian mineral is hornblende instead of augite, and (2) the only known occurrences of these rocks are adjacent to intrusive masses of quartz diorite.

FELSITES AND PYROCLASTIC ROCKS

Felsite and variegated pyroclastic rocks are scarce on Mount Chase but are more abundant both to the northeast and southwest. The southeasternmost exposure of volcanic strata in the vicinity of Bear Mountain and Seams Brook consists of sheared green rock that contains abundant fragments or ellipsoidal boulders and cobbles of greenstone in a matrix of finer grained greenstone and white-weathering chert. The fragments have a punky vesicular rind and are rich in magnetite. A similar rock on Wardsworth Mountain contains large rounded fragments of greenstone as much as 20 inches in length in an aphanitic red matrix. These rocks could be agglomerates, flow-breccias, or debris flows.

The southeasternmost exposure of volcanic strata along the Mud Lake tote road west of State Highway 11 is of sheared rock rich in phenocrysts of quartz. The rock exhibits vague bedding or flow layering. Two thin sections show that the rock contains, in addition to quartz, a few grains of alkalic feldspar. These grains commonly have cores of quartz. The quartz phenocrysts are anhedral masses as much as 2 mm in diameter that consist of many individual grains with sutured contacts. The groundmass or matrix consists of fine-grained quartz, sericite, and minor calcite. Quartz appears as masses and large angular grains in two other thin sections from the same exposure but from more resistant strata. Those sections also contain a few euhedral grains of alkalic feldspar and a few small crystals of plagioclase. Calcite, pyrite, and magnetite are locally abundant. The exposed rocks are probably silicified rhyolite lavas or rhyolitic tuffs with intercalated ash-fall tuff. Similar rocks crop out in places farther along the Mud Lake tote road, at Seams Brook, on Mattawamkeag Hill, and on Shoaler Mountain.

SLATE

A thin zone of even-bedded dark-gray and purple slate and siltstone about 100 feet thick crops out northwest of Bear Mountain on the boundary between Moro and Hersey Townships, on the McManus tote road, at the Maine Forest Service cabin on the south slope of Mount Chase, and on Wardsworth Mountain. These outcrops form a nearly straight line; the slate is inferred, therefore, to be continuous between the outcrops in this area (pl. 1). On Bear Mountain, along the tote road that leads to Pleasant Lake, dark-gray slate is in contact with a massive-weathering medium-grained sill of spilite. A thin section of the slate taken a few feet from the contact indicates the rock is rich in quartz and contains green biotite, garnet, and abundant magnetite. The garnet and magnetite are concentrated in elliptical blebs whose long axes are parallel to cleavage planes. Magnetite makes up about 10 percent of the volume of the rock and was probably formed with garnet during the intrusion of the spilite. Thin-bedded purple-gray siltstone and gray chert crop out on the north side of the sill. These rocks are also rich in magnetite but contain no garnet.

STRATIGRAPHIC RELATIONS AND AGE

The volcanic rocks of the Mount Chase area overlie the Shin Brook Formation of Early or early Middle Ordovician age northwest of Pleasant Lake and are older than the graptolite-bearing slate of Middle Ordovician age on Kilgore Knoll. The possibility seems good, therefore, that the volcanic strata of Mount Chase are of Early or early Middle Ordovician age. The lavas are probably genetically related to the tuffs of the Shin Brook Formation and some flows may have accumulated simultaneously with them. The bedded tuffs of the Shin Brook Formation are exposed near Green Mountain, the Lane Brook Hills, and in the adjacent Shin Pond quadrangle.

SEDIMENTARY ROCKS AND GREENSTONE ON KILGORE KNOLL

Thin beds of fine-grained greenstone interbedded with black chert, black slate, and a few thin beds of green-gray quartzite crop out on Kilgore Knoll in what is probably a faulted anticline between the West Branch Mattawamkeag River and the old site of the Kilgore School. The black chert and slate give the strongest electromagnetic anomaly of any of the conductive strata in the Island Falls quadrangle.

The chert is coal black to blue black in the wet outcrop but when dry is medium gray. The chert is in beds a few inches to 5 feet thick and shows poorly defined cleavage. The interbeds of black slate, on the other hand, are well cleaved. Some of the black slate in a single outcrop contains numerous pyritized graptolites.

The following graptolites were found in black cherty slate at locality 5 (pl. 1). They were identified by W. B. N. Berry and are of Normanskill, Middle Ordovician age.

?*Amplexograptus*
Climacograptus bicornis Hall
Climacograptus phyllophorus Gurley?
Climacograptus sp.
Cryptograptus tricornis Carruthers
Dicellograptus sp.
?*Didymograptus*
Glyptograptus teretiusculus (Hisinger)
Glyptograptus sp.
Hallograptus mucronatus (Hall)
Leptograptus sp.
Orthograptus sp.

In outcrop, the fine-grained greenstone has a slightly different appearance from the spilite of Mount Chase. The difference is due to an overall lighter green color and a lack of amygdules, which are common in the fine-grained spilite in the vicinity of Mount Chase. Two thin sections were examined: one is rich in actinolite and clinozoisite, and calcite is scarce; the other is rich in calcite and chlorite and contains little or no actinolite, clinozoisite, or epidote. The feldspar is cloudy albite in both thin sections, and neither one contains quartz. The original texture was probably pilotaxitic, and the rocks may have been altered basalts or spilites.

ROCKABEMA QUARTZ DIORITE

The name Rockabema Quartz Diorite is here given to the intrusive rock that crops out in the vicinity of Rockabema Lake, Pleasant Lake, and Hastings Brook in T. 6, R. 6 W., and also in Moro and Merrill Townships, R. 6 W. The best exposures occur along the northeast and north shore of Rockabema Lake, here designated as the type locality. Other good exposures occur along the southeast shore of Mud Lake, and, locally, along the south shore of Pleasant Lake.

Rockabema Quartz Diorite occupies the central part of the Weeksboro-Lunksoos Lake anticline in the vicinity of Rockabema and Pleasant Lakes, where it forms a large stock about 3 miles in width. It thins at the west boundary of the quadrangle but widens in the Shin Pond quadrangle near the Shin Ponds. A smaller stock of quartz diorite has been injected lit-par-lit into the Grand Pitch Formation and volcanic rocks of the Mount Chase area in the vicinity of East and West Hastings Brooks. Here quartz diorite makes up about 50–60 percent of the total rock volume. Two small plugs of quartz diorite crop out on Green Mountain and Frost and Adams Ridge.

The intrusive igneous rock is not as resistant to erosion as surrounding strata, and outcrops are few. Exposures of the quartz diorite weather to form massive rounded outcrops, although cleavage is everywhere fairly well defined.

Along the southeast and east margins of the stock at Rockabema Lake, and in the smaller plutons at East Hastings Brook, Green Mountain, and Frost and Adams Ridge, the quartz diorite is so intensely sheared and brecciated that it is almost a schist. Exposures between West Hastings Brook and the northeast shore of Rockabema Lake indicate that sheared rock in the stock becomes gradually less abundant westward from West Hastings Brook. Along the northeast and north shores of Rockabema Lake the rock is not schistose and shear zones are rare. The significance of the schistose structure is not well understood. The shearing is possibly related to the inferred fault zone that forms the southeast boundary of the quartz diorite mass near Rockabema Lake; however, the fact that the smaller plutons are sheared throughout suggests that most of the schistose structure resulted from crushing and shearing during the intense Acadian folding, when the sedimentary and volcanic rocks were jammed tightly against the intrusive masses.

PETROGRAPHY

The large stock at Rockabema and Pleasant Lake is a composite mass containing two distinctly different types of rock. These are shown separately (pl. 1), but the contact between the two is very poorly defined and was never directly observed in the field.

Both types of rock are characterized by abundant crystals of quartz, but the rock at Rockabema Lake is very nearly equigranular whereas that at Pleasant Lake is distinctly porphyritic. At Rockabema Lake the rock is gray to green gray and medium grained and contains about 31 percent quartz, 10 percent potassium feldspar, 34 percent plagioclase, 5 percent hornblende, 12 percent chlorite, 6 percent epidote, and 1 percent calcite. The plagioclase is very cloudy and has been altered almost completely to albite, epidote, calcite, sericite, and a few flakes of chlorite. Most of the chlorite in the rock has been altered from hornblende, but some appears to have altered from biotite. Magnetite is sparse and is localized with chlorite and epidote in pseudomorphs after hornblende. Tiny veinlets of epidote and calcite are scattered through the rock. Quartz was formed after crystals of plagioclase and hornblende and fills interstices between them. Most of the crystals are 1–2 mm in diameter; a few quartz crystals are as long as 5 mm, and a few hornblende crystals 10 mm. The texture is hypidiomorphic granular.

The rock at Pleasant Lake contains large grains of quartz and plagioclase as much as 10 mm long in a groundmass of much smaller crystals of plagioclase, quartz, and chlorite. The quartz phenocrysts, commonly aggregates of several individual crystals, are more erosion-resistant than other crystals and therefore stand out on the surface of outcrops. Many of the large quartz crystals have nearly euhedral outlines and are surrounded by smaller grains of plagioclase. These quartz crystals were probably formed early during the crystallization of the magma. Other quartz crystals are late and fill interstices between grains of plagioclase and mafic pseudomorphs filled with chlorite, epidote, and locally sphene. Most of the mafic pseudomorphs appear to be after biotite rather than hornblende and contain abundant tiny radioactive zircon crystals that produce halos in the surrounding chlorite. The plagioclase in the rock at Pleasant Lake is intensely altered to calcite, epidote, sericite, and chlorite. The cores of the plagioclase crystals are much more altered than the outer hulls. Twinning is indistinct. The plagioclase remnants are albite or sodic oligoclase.

East and southeast of Mud Lake in the vicinity of Duck and Pickett Mountain Ponds, and northeast of Pleasant Lake near Spring Brook, the groundmass of the quartz diorite is much finer grained. This textural difference probably resulted from more rapid cooling of the intrusive mass toward the edges of the stock. The rock in these areas is green and weathers to white or light gray; near Pickett Mountain Pond it contains large xenoliths of ophitic greenstone derived from the spilite lavas of the Mount Chase area. Quartz forms the largest and most conspicuous phenocrysts in the fine-grained border or selvage of the rock. A thin section from Spring Brook contains about 55 percent phenocrysts, of which 35 percent is quartz, 61 percent plagioclase, and 4 percent mafic pseudomorphs. The plagioclase phenocrysts are albite in composition and contain abundant zoisite. The mafic pseudomorphs are filled with chlorite and sphene and are probably altered from titanium-rich biotite. The groundmass consists of albite, sericite, quartz, and chlorite. The green fine-grained border rock is considered to be contiguous with megascopically identical rock in the adjacent Shin Pond quadrangle.

The lit-par-lit injected rock at East Hastings Brook is mostly light gray and equigranular. In hand specimen it closely resembles the rock exposed at Rockabema Lake. In places, however, as in the bed of East Hastings Brook about 1,000 feet south of State Highway 212 between Knowles Corner and Smyrna Mills, the rock is porphyritic and green. Two thin sections show strong cataclastic textures. Mafic minerals have altered completely to chlorite; feldspars have altered in part to sericite, calcite, and chlorite; and quartz crystals have been strained and shattered. Pyrite is fairly abundant.

The intrusive rocks exposed on Frost and Adams Ridge and on Green Mountain were not examined in thin section. The rocks contain abundant phenocrysts of quartz, are green or gray green, and appear megascopically identical with the chlorite-rich porphyritic rock exposed near Pleasant Lake.

CHEMICAL COMPOSITION

Three chemical analyses (table 3) of Rockabema Quartz Diorite indicate that the nearly equigranular rock at Rockabema Lake is 10–11 percent poorer in silica than the porphyritic rock at Pleasant Lake and is richer in total iron, magnesium, calcium, and alkali metals. The rock at Rockabema Lake contains 1.73–1.93 percent K_2O whereas that at Pleasant Lake contains only 0.38 percent. The very low K_2O content at Pleasant Lake is unusual because the principal original mafic mineral was probably biotite. Apparently, some potassium ions migrated from the rock at Pleasant Lake during alteration; the relatively high Na_2O content with respect to K_2O suggests that some potassium ions in original feldspar lattices were replaced by sodium ions. Replacement is suggested also by the fact that at Shin Pond the selvage-quartz diorite, which is considered to be contiguous with the porphyritic border rocks in the Island Falls quadrangle, is relatively rich in K_2O (table 4). The high K_2O content of the rock at Shin Pond is not the result of assimilation of adjacent country rock, as the country rock there is metabasalt or spilite, characterized by very low K_2O.

TABLE 3.—*Chemical analyses of Rockabema Quartz Diorite*

Lab. No.	[1] 155149	[2] H3643	[2] H3644
Field No.	59 IF 9-1-1	61-8-15-1	61-8-16-9
SiO_2	72.7	62.69	61.13
Al_2O_3	14.0	15.83	15.02
Fe_2O_3	.7	.72	.48
FeO	2.2	4.37	4.79
MgO	.69	2.34	2.82
CaO	3.0	4.90	3.80
Na_2O	4.5	3.19	3.26
K_2O	.38	1.73	1.93
H_2O	1.3	2.05	2.68
H_2O-	----------	.05	.06
TiO_2	.35	.71	.67
P_2O_5	.10	.10	.10
MnO	.04	.12	.13
CO_2	<.05	.95	2.83
Cl	----------	.01	.00
F	----------	.04	.04
Total	----------	99.80	99.74
Less O	----------	.02	.02
	100	99.78	99.72

[1] Rapid rock analysis by P. L. D. Elmore, S. D. Botts, I. H. Barlow, and Gillison Chloe.
[2] Standard rock analyses by P. M. Buschman.

59 IF 9-1-1. From the south shore of Pleasant Lake.
61-8-15-1. From the northeast shore of Rockabema Lake.
61-8-16-9. Intensely sheared; from West Hastings Brook.

Sample 61-8-16-9 is of highly sheared nearly schistose rock just east of Rockabema Lake. In chemical composition it is almost identical with nonsheared rock from the northeast shore of Rockabema Lake (sample 61-8-15-1); it is richer in calcite. (See high CO_2 content in analysis.) The similarity of the two rocks indicates that the shearing and the development of a nearly schistose structure in the quartz diorite did not appreciably affect the overall chemical composition.

AGE

The Rockabema Quartz Diorite intrudes the Grand Pitch Formation of Cambrian(?) age, the Shin Brook Formation of Early Ordovician or early Middle Ordovician age, and the volcanic rocks of the Mount Chase area, which are about the same age as the Shin Brook. These relations are the only direct evidence of age; they indicate that the quartz diorite is later than Early Ordovician in age. Neuman (1960) first called attention to the occurence of the quartz diorite and gave two lines of evidence that the quartz diorite is probably of Ordovician age. An earlier age than Acadian is indicated by the intense alteration and deformation of the rock. All the granite intrusive masses of Acadian age in the Smyrna Mills quadrangle and other areas in northern and eastern Maine are relatively unaltered and uncleaved and are surrounded by hornfels rims. These hornfels rims commonly cause aeromagnetic anomalies; no significant anomalies occur along the border of the Rockabema Quartz Diorite except where magnetic volcanic rocks form one side of the contact. A pre-Silurian age is suggested by the occurrence of pebbles, cobbles, and boulders of quartz diorite in conglomerate lenses of Silurian age that crop out southeast of Mount

Chase in the Island Falls quadrangle (pl. 1), and in several belts in the adjoining Shin Pond and Stacyville quadrangles.

Neuman's conclusion that the fragments of quartz diorite in the conglomerate were derived from the Rockabema Quartz Diorite is supported by petrographic and chemical data. Thin sections of several cobbles of quartz diorite from conglomerate exposed in the Island Falls and Shin Pond quadrangles indicate that the detrital material is nearly identical with the Rockabema intrusive rock. A chemical analysis of a boulder from a conglomerate lens exposed about 2½ miles west of the Island Falls quadrangle near the Allsbury Road (table 4) indicates that the composition of the boulder is very similar to the composition of the Rockabema Quartz Diorite in the stock at Shin Pond.

TABLE 4.—*Comparison of Rockabema Quartz Diorite near Shin Pond with an igneous boulder from a conglomerate lens near Shin Pond*

	Rockabema Quartz Diorite	Igneous boulder
Lab. No	155148	H3645
Field No	59SP8-28-1	61-10-13-1
SiO_2	68.7	66.47
Al_2O_3	15.1	15.45
Fe_2O_3	.9	.39
FeO	2.7	3.12
MgO	1.2	2.27
CaO	1.8	1.76
Na_2O	3.6	3.87
K_2O	3.4	2.66
H_2O	1.7	2.11
TiO_2	.46	.45
P_2O_5	.12	.13
MnO	.10	.08
CO_2	.64	.84
F	Not determined	.05
Total	100	99.65
Less O	----------	.02
	----------	99.63

59SP8-28-1. Rapid rock analysis by P. L. D. Elmore, S. D. Botts, I. H. Barlow, Gillison Chloe. Sample from outcrop at upper end of Lower Shin Pond in roadcut of Shin Pond Road about 2 miles west of Island Falls quadrangle.

61-10-13-1. Standard rock analysis by P. M. Buschman. Sample from boulder in conglomerate lens exposed about 1 mile west of Allsbury Road-Shin Pond Road intersection and 2½ miles west of Island Falls quadrangle.

The Rockabema Quartz Diorite can, therefore, be dated conclusively between two limits; it is younger than the volcanic strata of Early or early Middle Ordovician age, which it intrudes, and is older than the conglomerate lenses of Silurian age. It is here classed as Ordovician.

ORDOVICIAN OR SILURIAN SYSTEM

MATTAWAMKEAG FORMATION

The Mattawamkeag Formation is named herein after the West Branch Mattawamkeag River. The best exposures and the type locality are at Warren Falls in the eastern part of the quadrangle near the east boundary of Hersey Township. The formation crops out in an area about 3 miles wide and about 10 miles long through Hersey, Dyer Brook, and Merrill Townships.

The rocks in the Mattawamkeag consist of about 50 percent slate and 50 percent siltstone and graywacke. The rocks are thin and thick bedded and are very similar to those in the Allsbury Formation, except that the slates are lighter colored and are not conductive.

GRAYWACKE

Graywacke in the Mattawamkeag Formation is almost entirely feldspathic, containing only small amounts of lithic fragments and averaging less than 50 percent quartz. The graywacke occurs in beds that range in thickness from about an inch to 25 feet but average about 1 foot. The beds are very well graded nearly everywhere; the finest examples of graded beds in the Island Falls quadrangle are in the Mattawamkeag Formation. The bases of the beds of graywacke commonly lie on scoured surfaces, and the beds in many places grade upward from coarse grit to fine slate within a vertical distance of 1 foot.

The graywacke contains abundant matrix consisting dominantly of fine-grained quartz, sericite, and chlorite. Because of the abundance of matrix and a general lack of siliceous cement, the beds are structurally incompetent, and slaty cleavage is almost as well developed in the graywacke as in the adjacent beds of mudstone and siltstone. In places the beds are intensely sheared and almost schistose. Angular to subangular grains of quartz and plagioclase form the framework of the graywacke (fig. 3).

SLATE AND SILTSTONE

Slate (mudstone) and siltstone are medium gray, green gray, and, in a few places, dark gray. Both show very well defined cleavage and, in places, grade to mica-rich phyllite. The beds of mudstone and siltstone are interbedded with graywacke and are 1 inch to 10 feet thick. In many places the rocks display fine cross laminations or convolute bedding.

In two thin sections of silty slate, both bedding and cleavage are visible; concentrations of quartz grains outline the bedding, and oriented shreds and tiny plates of sericite outline the cleavage. Chlorite is common.

STRATIGRAPHIC RELATIONS AND AGE

No fossils have been found in the Mattawamkeag, and the age of the formation is very uncertain. Top directions determined from graded beds along the northwest and southeast flanks of the area of outcrop

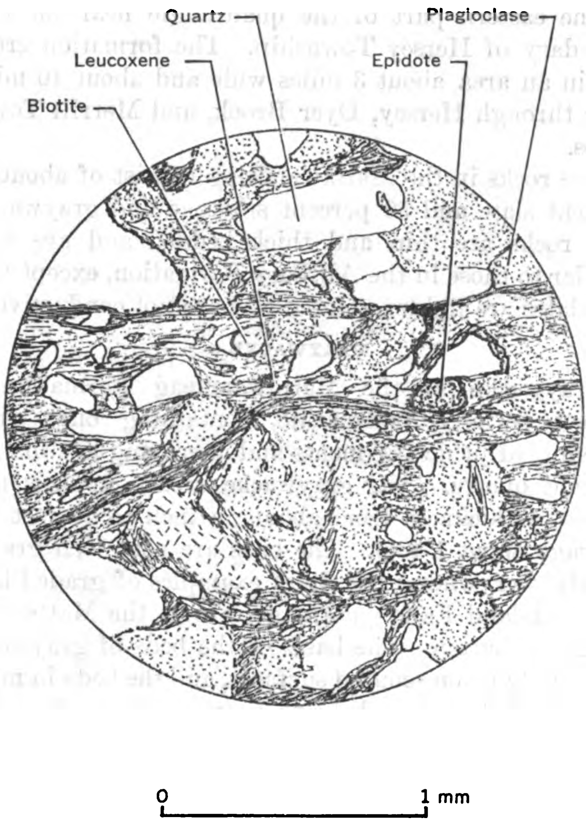


FIGURE 3.—Green-gray medium- to coarse-grained feldspathic graywacke from the Mattawamkeag Formation. The rock consists of large grains of quartz and plagioclase in a matrix of quartz, sericite, chlorite, and calcite. Biotite and epidote occur as sparse detrital grains. Plagioclase is intensely sericitized and many grains are not readily distinguished from the matrix. Sample 59 IF 7-30-7, about 0.3 mile east of the West Branch of the Mattawamkeag River on Halls Corner Road.

indicate that the Mattawamkeag is older than both the Allsbury Formation and the rocks of Island Falls and is probably, therefore, of Ordovician age. However, the possibility cannot be precluded that part or all of the Mattawamkeag is of Silurian age. It is here classed as Ordovician or Silurian.

SILURIAN SYSTEM

Silurian rocks crop out on both flanks of the Weeksboro–Lunksoos Lake anticline (Pavlides and others, 1964, p. C28), but do not in themselves define this large fold. (See "Structure.") The strata in the two areas are distinctly different and reflect different depositional environments caused, at least in part, by the anticlinal barrier which was topographically high at the start of the Silurian Period. The rocks in the southeastern part will be described first.

CONGLOMERATE

A belt of strata consisting dominantly of gray to green-gray coarse-grained conglomerate, but containing interbeds of coarse grit, conglomeratic graywacke, and minor amounts of gray slate, crops out east of Patten along the Penobscot-Aroostook County line. The belt extends northward and northeastward through Crystal Lake, Seams Brook, and Houston Brook. Smaller patches of conglomerate crop out in the vicinity of Bear Brook and Alder Brook, and southwest of Lyman Brook.

The conglomerate is characterized by abundant pebbles and cobbles of light-gray and green-gray chert or felsite that commonly weather white. The rock contains, in addition to the chert or chertlike felsite, fragments of quartzite, quartz porphyry, and ophitic greenstone. A pebble count from a single outcrop along the Penobscot-Aroostook County line gave the following percentages: Chert or felsite, 42 percent; green volcanic rocks (mostly quartz rich, some quartz free), 28 percent; quartzite, 15 percent; quartz porphyry, 15 percent. Most of the quartz porphyry is identical with the Rockabema Quartz Diorite.

Pebble-sized fragments are most common in the conglomerate, but boulders and cobbles are locally abundant. In the vicinity of Crystal Lake, the conglomerate contains angular boulders of actinolite-rich igneous rock as large as 2 feet across and 4 feet long. A few boulders of limestone and jasper occur locally, and in places slabs and boulders of slate are abundant. Most fragments, except the slate, are fairly well rounded. The matrix consists of quartz, chlorite, plagioclase, and sericite. The conglomerate occurs in even beds that range in thickness from several inches to several tens of feet.

Lenses of conglomerate that are identical with those in the Island Falls quadrangle crop out between the Allsbury Formation and the volcanic rocks of the Mount Chase area along the southeast limb of the Weeksboro–Lunksoos Lake anticline in the adjacent Shin Pond quadrangle. The possibility exists, therefore, that the conglomerate exposed east of Patten lies along the east limb of a broad synclinorium and is generally continuous at depth with the conglomerate at Shin Pond. The thickness of the conglomerate is believed to range from 0 to as much as 4,000 feet, which is the estimated maximum thickness of the belt east of Patten.

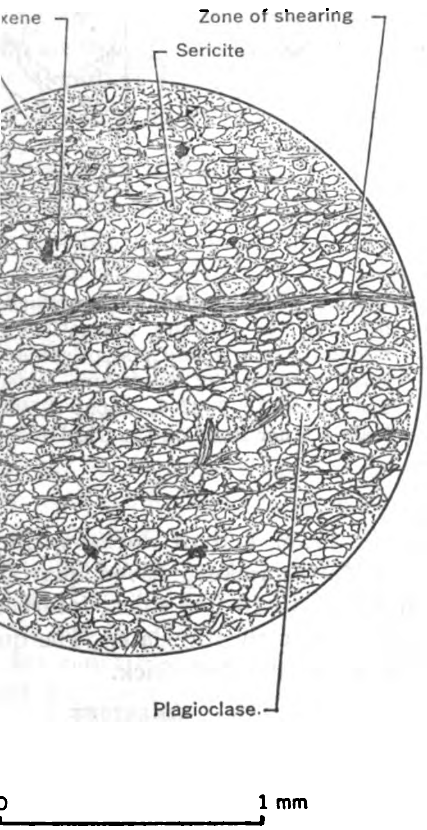
Recent finds of fragmentary brachiopods and other fossil debris by Neuman (1967) in the Stacyville quadrangle indicate an Early Silurian age for the conglomerate lenses.

LLSBURY FORMATION

Formation is named herein from ex-
ɔadbed and roadcuts of the Allsbury
area, in the Island Falls and Shin
es. The formation crops out in a
he vicinity of the road and consists
;raywacke and dark-gray, black, and
n beds of quartzite and coral-bearing
locally and were mapped separately.
k-gray and black slates in the forma-
ve and were traced by electromagnetic
ınductive zones consist mostly of black
small amounts of graywacke. They
ıe nonconductive zones in that sand-
:e) is less abundant and the slate is

GRAYWACKE

:urs in graded beds and laminae that
ss from fractions of an inch to several



ery fine grained feldspathic graywacke
lsbury Formation. The rock is noncal-
consists of about 40 percent angular
4 percent plagioclase in a matrix of
ite, and chlorite. A few crystals of bio-
w chloritized mafic minerals are present.
E–109, 2,800 feet east of Aroostook
way along farm road leading east from
l.

—3

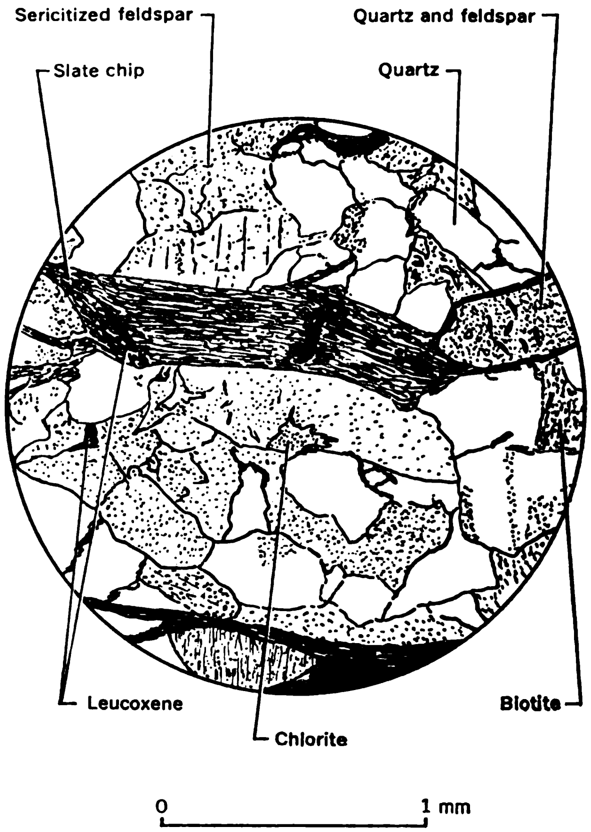


FIGURE 5.—Slate-bearing graywacke from the Allsbury Formation. The rock is a mosaic of quartz and feldspar and contains abundant chips of slate. The chips are very micaceous, containing both muscovite and biotite. Some chips are nearly black in transmitted light because of their abundant carbon. Except for the chips, the rock is moderately well sorted, and most grains range in diameter from 0.3 to 0.8 mm. The grains are commonly not single crystals of quartz and feldspar, but are rock fragments containing both minerals. Many fragments display micrographic intergrowth of quartz and feldspar. Grains of perthite are common. Most of the feldspar has been extensively sericitized. Sparse films of dense mica between the grains indicate an original clay or mud cement. Sample 59 IF 7–30–4, north side of Batesville Road about 2,000 feet east of Bates Cemetery.

tens of feet. The graywacke (figs. 4 and 5) contains, on the average, more than 30 percent of detrital matrix composed of sericite, quartz, sericitized and calcitized plagioclase, chlorite, carbon, and a few grains of biotite. The framework fraction is quartz and albite; slate granules, cobbles and pebbles; and chloritized mafic minerals. Quartz makes up less than 50 percent of the volume, and plagioclase varies from about 5 percent to more than 40 percent. Most of the graywacke is pyritic. Cataclastic textures are marked in most thin sections; in outcrop the graywacke displays well-defined cleavage and in many places is nearly a sericite schist.

SLATE

Thin sections of three dark-gray and black slates from conductive belts reveal that the principal mineral is quartz; chlorite, sericite, and carbon occur in lesser amounts. Rutile (verified by X-ray) is abundant as tiny needles. Tiny grains of tourmaline are common and pyrite is abundant, apparently occurring as two or more generations of crystals. The earlier pyrite crystals are surrounded by quartz. Magnetite is locally abundant and gives rise to small aeromagnetic anomalies.

The X-ray analysis of the blackest of the dark slates from a zone giving one of the strongest electromagnetic anomalies in the Allsbury Formation indicates that the carbon is not in the form of graphite (Theodore Botinelly, written commun., 1961). A thin section of the slate shows carbon in the form of spherical blebs or oolites 0.002–0.01 mm in diameter. Electron photomicrographs of carbon residue remaining after silicate minerals in the slate were dissolved in hydrofluoric acid, by a method described by Neuerburg (1961), show that the carbon oolites are hollow. Prior to treatment in acid the blebs or oolites had centers of silicate minerals—probably tiny grains of quartz. The conductivity of the slate results from the fact that the carbon oolites are interconnected and provide a continuous path for current to follow.

Thin sections of three green slates from the Allsbury show that they differ from the dark-gray and black slates only in their lower content of carbon. They consist mostly of quartz, sericite, and chlorite. Rutile and pyrite are common.

The green slates are confined mostly to the nonconductive zones in the Allsbury and are interbedded with gray and green graywacke.

QUARTZITE

Thin lenses of quartzite crop out between the Allsbury Road and State Highway 11 near Sargent and Houston Brooks in southeastern Mount Chase Township, at Jackson Sluice in Moro Township, and at Hale and Houston Brooks and near the Old Grub Road in Hersey Township.

The quartzite in southeastern Mount Chase Township, at Houston and Hale Brooks, and in the vicinity of the Old Grub Road consists of a single bed about 30 feet thick. The quartzite is pale tan gray and weathers tan gray or brownish gray. It is medium to coarse grained and locally contains quartz grains as large as 2 mm in diameter. A thin section from an exposure along the Old Grub Road (fig. 6) contains 73 percent quartz, 11 percent plagioclase, 6 percent potassium feldspar, 3 percent igneous rock fragments, and 6 percent chlorite and sericite. Accessory minerals include zircon, pyrite, garnet, magnetite, leucoxene, and apatite.

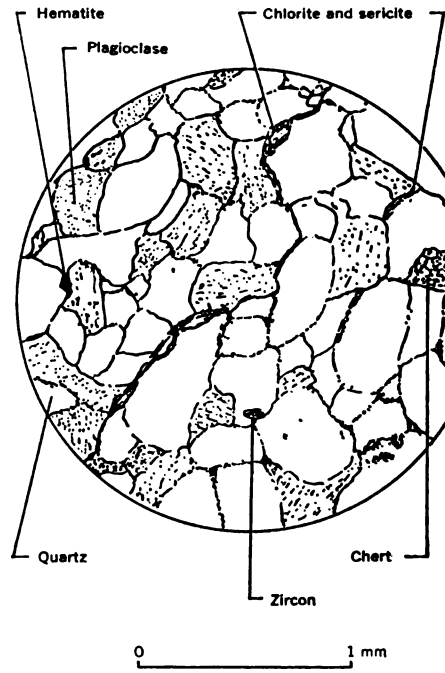


FIGURE 6.—Medium- to coarse-grained arkosic quartzite from the Allsbury Formation. The rock is a mosaic of quartz and plagioclase and contains very small amounts of potassium feldspar and chert. Sample 59 IF 7-27-7, about 1,500 feet south of Halls Corner Road on the Old Grub Road.

At the lower end of Jackson Sluice on the West Branch Mattawamkeag River, quartzite occurs in beds a few inches to 10 feet thick, interbedded with thinly laminated gray pyritic slate. The quartzite and slate zone is about 100 feet thick.

LIMESTONE

About 50 feet of thin- and thick-bedded medium- to purple-gray, buff-weathering limestone and calcareous slate or phyllite is exposed in the ditches and adjacent fields of Mill Road between Batesville and the site of the old Kilgore School. A single ledge of dark-gray limestone less than 20 feet in width is exposed in Bradford Brook, and several isolated ledges or massive boulders of medium to light-purple-gray limestone are exposed in a cedar swamp between Jackson Sluice and Kilgore Knoll in the vicinity of an old limestone kiln. The latter exposures are unusual for such a humid area in that the limestone weathers to massive boulders in the swamp, and the adjacent slate is almost completely covered. Early settlers quarried limestone from the massive boulders and burned or calcined the rock in the nearby kiln.

A thin section of limestone from the kiln area indicates that the rock is nearly pure calcite and contains less than 1 percent quartz as the only impurity. Grains of calcite averaging slightly less than 1 mm in size constitute the framework fraction (and major part) of the rock, and the interstices between the framework grains are filled with tiny grains of calcite and a few grains of quartz less than 0.1 mm in diameter. Locally, the rock contains abundant crinoid columnals as much as half an inch in diameter and fragments of tabulate corals. According to R. B. Neuman (oral commun., 1962), none of this material is diagnostic of age, although the large crinoid columnals suggest a post-Ordovician age.

At Mill Road the limestone is interbedded with limy siltstone and gray calcareous slate and phyllite. The limestone contains abundant crinoid columnals, as in the kiln area, and is richer in fragments of tabulate corals.

LIMY BEDS AT MILL BROOK

Thin-bedded silty limestone and limy siltstone crop out at Mill Brook northeast of Batesville. The beds are not believed to correlate with the coral-bearing limestone beds just described. They average less than 4 inches thick, are gray to dark gray, and resemble very closely the thin-bedded limestone member of the rocks of Island Falls.

The beds appear to be isolated in the vicinity of the brook and are not shown separately on the geologic map (pl. 1). They were not found either to the northeast or southwest, although they may extend for considerable distances in both directions. The total thickness is probably less than 200 feet. Structural data are few in the area, and it is not known whether the calcareous strata are older or younger than the surrounding slate and graywacke.

STRATIGRAPHIC RELATIONS AND AGE

Neuman (written commun., 1962) found monograptids of Early Silurian age in conductive slate at several localities along the projected strike of the Allsbury Formation in the Sherman quadrangle just south of the Island Falls quadrangle. According to Neuman the rock is medium-gray to dark-gray pyritic slate and siltstone, interlaminated with sandstone layers ½–¾ inch thick. The lithology is typical of the Allsbury, and these occurrences, together with the fragmentary brachiopods found in the underlying conglomerate lenses by Neuman (1967), establish the Allsbury Formation as Early Silurian in age.

The thickness of the Allsbury cannot be accurately determined because the rocks are tightly folded. It is probably a minimum of 1,000 feet in the northeast and at least 4,000 feet in the southwest.

ROCKS OF ISLAND FALLS

Thin-bedded silty limestone and calcareous siltstone and sandstone crop out in the extreme southeast corner of the Island Falls quadrangle. The rocks are well exposed at Island Falls and on May Mountain just northeast of the falls, but elsewhere in areas of low relief and abundant swamps they are very poorly exposed. Inasmuch as the limestone is abundant, the rocks are informally divided for mapping purposes into a limestone unit and a slate and sandstone unit.

LIMESTONE

Thin-bedded silty limestone and calcareous siltstone crop out in three narrow belts. The strata are even bedded and range in thickness from about a quarter of an inch to a foot. The calcareous siltstone averages less than 1 inch in thickness, and the silty limestone, which weathers to form recessed bands between ribs of siltstone on outcrop surfaces, averages less than 3 inches. The banded pattern is characteristic and is especially pronounced in the streambed exposures.

Rocks in the limestone unit are dark gray and weather blue gray and brown gray. Most of the beds are finely cross laminated, and drag folds are abundant. Veins of white calcite from a fraction of an inch to several inches thick are a conspicuous feature. The veins generally parallel the cleavage, but in places they crosscut both cleavage and bedding.

The limestone unit is placed in the same cartographic unit as the slate and sandstone because good exposures in several streambeds indicate that the contacts are gradational. The possibility exists that the unit correlates with the "ribbon rock" member of the Meduxnekeag Formation of Middle Ordovician to Early Silurian age, described by Pavlides (1962, p. 11–12), and Pavlides, Neuman, and Berry (1961, p. 65–67).

The limestone unit probably ranges in thickness from 0 to 3,000 feet.

SLATE AND SANDSTONE

At Island Falls and May Mountain, the rocks of Island Falls consist of medium-gray, green-gray, and dark-gray thin-bedded slate, siltstone, and very fine to fine-grained sandstone. Thin beds of silty limestone averaging less than 6 inches thick occur throughout. They are rare at the falls but are fairly abundant in exposures a short distance above and below the falls. The thickness of sandstone beds averages about 3 inches but is locally as much as 3 feet. The beds show fair grading and nearly everywhere are finely cross laminated.

The sandstone is quartzitic, and, in most exposures, calcareous. In one thin section, calcite makes up about 30 percent of the volume and quartz about 50 percent. The remainder of the rock consists of chlorite, sericite, and carbon . The volume of quartz determined in this thin section is believed to be about minimum for the sandstone in the Island Falls rocks. The abundance of quartz and calcite in the sandstone is a distinctive feature contrasting with the scarcity of these minerals in the adjacent feldspathic graywacke of the Mattawamkeag Formation.

The major constituents in the slate are quartz, sericite, calcite, chlorite, and carbon. A few grains of tourmaline are present, and the rock abounds in tiny needles of rutile.

The thickness of the slate and sandstone unit is probably less than 1,000 feet in the northwesternmost outcrops and reaches a maximum of 3,000 feet near Island Falls. (See section *A–A′*, pl. 1.)

STRATIGRAPHIC RELATIONS AND AGE

Graptolites of Early, Middle, and early Late Silurian age have been found at several localities in a slate, siltstone, and quartzite sequence that crops out east of the Island Falls quadrangle in the Smyrna Mills quadrangle along the projected strike of the rocks of Island Falls (Pavlides and Berry, 1966). The nearest fossil locality is in Dyer Brook Township in a roadcut of U.S. Highway 2 about 3 miles northeast of the town of Island Falls. The rocks in the roadcut contain fossils of Middle Silurian age and are identical with the rocks at May Mountain in the Island Falls quadrangle. Thus, part of the sequence of Island Falls is of Middle Silurian age. The occurrence of the rocks of Island Falls stratigraphically above the Mattawamkeag Formation suggests that the lower part of the sequence is of Early Silurian age, inasmuch as it seemingly occupies the same stratigraphic position as the Allsbury Formation. If this inference is valid, the relative paucity of carbon and pyrite in the Island Falls rocks as compared with the Allsbury indicates that the Island Falls rocks were deposited in a more open marine environment. Louis Pavlides (written commun., 1965) suggested the possibility that the Mattawamkeag anticline (see "Structure") acted as a barrier between two basins during the deposition of the Allsbury and Island Falls rocks and thus enabled contrasting strata of similar age to form. This is a plausible explanation and may be a valid one; however, the data are inconclusive as to whether the Mattawamkeag anticline existed at all prior to the Acadian orogeny. The fact that the Island Falls rocks do contain carbon, although not as abundantly as the Allsbury, suggests that the depositional environments of the two units were similar. Perhaps the Allsbury Formation was deposited in a deeper basin of restricted circulation, a basin that lay nearer shore, as indicated by the relatively coarser clastics in these beds.

UNDIFFERENTIATED SEDIMENTARY ROCKS AND QUARTZ PORPHYRY

Undifferentiated rocks of Silurian age unconformably overlie the Grand Pitch Formation; they conformably underlie the Seboomook Formation in the vicinity of Lane Brook and the Lane Brook tote road in the northwestern part of the quadrangle. The rocks consist of conglomerate, limestone conglomerate, dark-gray sandstone, and slate, and include a thin sill or lava flow of quartz porphyry at the top.

The base of Silurian rocks in the vicinity of Lane Brook is marked by a bed of coarse conglomerate containing pebbles, cobbles, and boulders of quartzite, large slabs of dark-gray slate, and a few concretions or boulders of brown-weathering calcite or recrystallized limestone. Most of the material has been derived from the Grand Pitch. In this area the conglomerate has been intensely brecciated and pyritized. Northeastward from the exposures in Lane Brook the bed of slate- and quartzite-bearing conglomerate pinches out or has been faulted out, and the oldest Silurian rocks are gray limestone and limestone conglomerate containing abundant fragments and boulders of coral. In West Hastings Brook at the north boundary of the quadrangle, the limestone conglomerate is in direct contact with the Grand Pitch and near the contact contains many angular fragments of quartzite that weather to sharp knobs on the surface of the limestone outcrop. The limestone conglomerate is overlain by calcareous sandstone and slaty siltstone, which in turn are overlain by the Seboomook. The sandstone and siltstone are gray and weather to brown, tan, and brownish red.

The strata exposed near the bench mark at elevation 916 feet appear to be very different from those at West Hastings Brook. The topmost rock of the Silurian section is green-gray quartz porphyry that consists of about 50–60 percent phenocrysts (mainly plagioclase and quartz) and 40 percent groundmass composed of sericite, chlorite, and very fine grained quartz. The rock contains abundant fine-grained magnetite or ilmenite that occurs with chlorite in pseudomorphs after biotite or hornblende. The magnetite probably accounts for the small aeromagnetic anomaly that coincides with the outcrop belt of Silurian strata.

The first outcrop beneath the quartz porphyry consists of thin- and thick-bedded calcareous medium- to coarse-grained sandstone, sandy limestone, and dark-gray calcareous siltstone. The siltstone contains abundant fossils (loc. 1, pl. 1). It is finely laminated at 2- to 3-inch intervals and weathers punky and tan or brownish red. Coral-bearing limestone conglomerate crops out about 1,000 feet southeast of the fossiliferous siltstone locality and an estimated 300 feet below the siltstone; however, fossil data indicate the limestone conglomerate is younger than the siltstone; therefore, the two outcrops must be separated by a concealed fault.

A. J. Boucot examined three collections of fossiliferous calcareous siltstone from a single outcrop near the bench mark at elevation 916 feet (loc. 1, pl. 1.) and concluded that the beds are of late Early Silurian age. The following forms were identified:

Colln. 61–10–1–4
- *Nucleospira* sp.
- *Leptaena "rhomboidalis"*
- *Plectodonta* sp.
- *Resserella* sp.
- *Atrypa "reticularis"*
- *Stricklandia lens* cf. *ultima*
- corals
- *Clorinda* sp.
- rhynchonellids
- *Chilidiopsis*? sp.
- *Meristina* sp.
- *Encrinurus* sp.
- *Anastrophia*? sp.
- *Trigonirhynchia*? sp.
- rostrospiroid
- *Platystrophia*? sp.
- *Cyrtia* sp.
- *Striispirifer* sp.
- *Eospirifer* sp.
- *Howellella* sp.
- *Plectatrypa* sp.
- *Mesodouvillina*? sp.

Colln. 61–10–1–5
- *Encrinurus* sp.
- *Howellella* sp.
- rhynchonellid
- *Nucleospira* sp.
- *Atrypa "reticularis"*
- *Howellella* sp.
- dalmanellid

Colln. 61–10–1–3
- *Calymene*? sp.
- *Leptaena "rhomboidalis"*
- *Howellella* sp.
- *Dictyonella*? sp.
- rhynchonellid
- *Lissatrypa*? sp.
- *Plectatrypa*? sp.
- *Nucleospira* sp.

A Late Silurian age for the limestone conglomerate at sample locality 2 (pl. 1) is indicated by its corals, according to W. A. Oliver, Jr. (written commun., 1961).

Colln. 60–E–1
- Auloporoid coral (apparently in massive stromatoporoid
- *Cladopora* sp.
- *Cystihalysites* sp. of *C.* amplitubulata (Lambe)
- halysitid corals indet.
- *Favosites*? or *Thamnopora* sp.
- heliolitinid corals
- branching tabulate corals and (or) bryozoans
- indeterminate horn corals
- *Tryplasma*? sp.

The Silurian rocks are about 600 feet thick near West Hastings Brook and about 1,500 feet thick near the bench mark at elevation 916 feet.

DEVONIAN SYSTEM

SEBOOMOOK FORMATION

The Seboomook Formation (Boucot, 1961, p. 169–171) was named from Seboomook Lake east of the report area. At the type locality it consists almost entirely of cyclically layered dark sandstone and slate. It may be as much as 20,000 feet thick.

The Seboomook crops out in the northwest corner of the quadrangle and consists dominantly of alternating cyclically layered dark sandstone and slate in graded beds. The sandstone beds average about an inch in thickness, show good grading to slate, and weather to ribs on the surface of the outcrop. The interbeds of slate or mudstone average about the same thickness as the sandstone. Bedding in the formation is generally conspicuous, but locally, near Weeks Brook and on the ridge northwest of Weeks Brook, the formation grades to thick beds of sandstone and mudstone in which bedding is difficult to discern. The rocks in the Seboomook are dark gray to dark green gray and commonly display a weathered rind that is light gray or tan gray and about ¼–½ inch thick. A thin section of sandstone indicates the rock is feldspathic graywacke containing about 50 percent of detrital matrix. The framework fraction is mainly subangular and angular quartz and includes a few grains of potassium feldspar and plagioclase. The matrix is mainly silt-size quartz, sericite, and chlorite. Heavy minerals include zircon, leucoxene, tourmaline, and apatite, which appear as tiny grains.

The Seboomook conformably overlies rocks of Silurian age in the Island Falls quadrangle, but the base of the formation has never been directly observed, and a disconformity or a minor angular unconformity may be present. The formation is about 5,500 feet thick in the Island Falls quadrangle, as measured along the south limb of the Wadleigh Bog syncline.

GRANITE OF DE LETTE RIDGE

A small stock or broad dike of medium-grained to pegmatitic granite crops out south and east of De Lette Ridge in the Smyrna Mills quadrangle. Abundant granite float suggests the mass is also present in the Island Falls quadrangle. The granite has baked adjacent sedimentary rocks of Island Falls, obliterating the cleavage and making the rocks more resistant to erosion. The baked rocks form a resistant ridge or rim on the west and north sides of the intrusive mass.

The granite is light gray, has a xenomorphic-granular texture, and contains 32 percent quartz, 37 percent perthitic feldspar, 27 percent albite ($An_{.05}$), and about 4 percent muscovite. The plagioclase crystals have been slightly sericitized. Crystals of perthitic feldspar are the largest in the rock and range from about 3 mm to at least 20 mm in length. The granite weathers to large rounded blocks with no suggestion of cleavage, and the weathered surface is white and buff, and is commonly partly covered with a blue-black stain or varnish similar to desert varnish. In most places the granite is deeply weathered and feldspar crystals have altered to clay. At least 10 inches of surface rock must be removed before a fresh sample can be obtained.

QUARTZ MONZONITE AND GRANODIORITE OF THE ISLAND FALLS AREA

The presence of abundant float of quartz monzonite and granodiorite east of the town of Island Falls indicates that the large pluton in the adjacent Smyrna Mills quadrangle extends for a short distance into the Island Falls quadrangle. Pavlides and Canney (1964) named the mass the Pleasant Lake pluton after Pleasant Lake in the Smyrna Mills quadrangle. Potassium-argon age determinations of biotite (Faul and others, 1963) indicate a late Early or Middle Devonian age (385 million years) for the intrusive rocks.

STRUCTURE

The tectonic features and geologic history of northeastern Maine have recently been summarized by Pavlides, Mencher, Naylor, and Boucot (1964), who pointed out that the Paleozoic rocks throughout northeastern Maine are mostly incompetent pelites, limestones, and tuffs that have been thrown into steep-limbed folds. Local thick sequences of competent rocks such as those in the Chapman syncline 40 miles northeast of the Island Falls quadrangle are more gently folded and have moderate to gentle dips. In the Island Falls quadrangle the strata dip almost vertically; dips of less than 70° are uncommon even in the relatively competent volcanic rocks of the Mount Chase area.

The rocks in the Island Falls quadrangle reflect both the Taconic and Acadian orogenies and also an earlier orogeny that folded the Grand Pitch Formation prior to the deposition of the Shin Brook Formation of Early or early Middle Ordovician age. The earlier orogeny has been named the Penobscot disturbance by Neuman (1967). Evidence for the angular discordance between the Grand Pitch and Shin Brook Formations is found in several outcrops in the vicinity of Green Mountain and Townline Brook, where strata in the Shin Brook dip about 70° and strata in the Grand Pitch dip vertically. Ordovician strata were folded prior to deposition of conglomerate beds of Silurian age (Neuman, 1960; this report, p. 12). The conglomerate contains fragments believed to be derived from the Rockabema Quartz Diorite and from volcanic strata of the Mount Chase area. Such evidence suggests that the large Weeksboro–Lunksoos Lake anticline or an ancestral structural was formed during the Taconic orogeny. In the northwest part of the quadrangle Silurian beds angularly overlie the Cambrian(?) Grand Pitch Formation without intervening Ordovician strata. The lack of Ordovician strata, which are thick to the southeast, seemingly confirms the Taconic folding and subsequent deep erosion. In the southeast part of the quadrangle, however, Ordovician and Silurian rocks crop out side by side, show the same degree of deformation and metamorphism, and display no unequivocal evidence of being separated by an angular unconformity. The Taconic folding in the Island Falls area apparently gave rise to folds with broad intervening areas of relatively undisturbed strata, or a large fold that affected only the northwest part of the quadrangle.

During the Acadian orogeny the entire Island Falls area was intensely compressed, as shown by vertical dips in strata as young as Middle Silurian (the rocks of Island Falls) and steep dips in the Seboomook Formation of Devonian age.

Very weakly developed minor folds that are younger than cleavage in the southeast part of the quadrangle (see description of minor folds below) suggest that the Island Falls area was subjected to some tectonic activity younger than the main severe Acadian orogeny. This folding was not necessarily associated with igneous activity and probably reflects a late pulse of the Acadian folding.

FOLDS

MAJOR FOLDS

The principal fold in the Island Falls quadrangle is the large anticline or anticlinorium at Pleasant Lake, named the Weeksboro–Lunksoos Lake anticline (Pavlides and others, 1964, p. C28). It plunges gently southwestward across the northwestern part of the area and exposes the Grand Pitch Formation. Its northwest limb is delimited by several synclines, principally the one that passes through Green Mountain and the Lane Brooks Hills (section *A–A′*, pl. 1), within which Ordovician volcanic rocks dip at relatively gentle angles. The southeast limb of the anticline, however, is vertical or nearly so, and although faulted, it probably descends to considerable depth beneath the sedimentary strata of Ordovician and Silurian age to the southeast. These data suggest that the anticline is asymmetric. Pavlides and his collaborators (1964, p. C34) considered the Weeksboro–Lunksoos Lake anticline to be a northeast-trending fold whose southwest end near Lunksoos Lake in the Shin Pond quadrangle has been rotated to a southeast-trending fold by the drag of the Katahdin batholith. This conclusion may be valid; however, the anticline may have originally been north or northwest striking and the east limb may have been thrown into a series of northeast-trending folds by the severe Acadian folding. If this is so, the anticline at Pleasant Lake may not be the main fold. The fold at Pleasant Lake and the synclines at Green Mountain and Townline Brook may lie on the flank of a larger anticline whose axis is buried beneath the Silurian unconformity. This possibility is suggested by the apparent asymmetry of the anticlinal fold at Pleasant Lake, and by the Silurian strata resting directly on the Grand Pitch northwest of the synclines at Green Mountain and Townline Brook. If the anticline at Pleasant Lake is truly the crest of the main fold, it seems odd that only the northwest limb, which probably included thick sequences of competent volcanic rocks, has been stripped clean of Ordovician strata.

The rocks of the Grand Pitch exposed in the anticline are tightly folded and have been more intensely deformed and twisted by cross folding than any of the younger strata in the quadrangle. The overall strike of beds in the Grand Pitch is northeast, but in many areas this direction is masked by local crinkles and minor folds, and no attempt was made to map individual folds within the formation. The projection of the anticline through the area of Grand Pitch northeast of Pleasant Lake is based on the occurrence of conductive strata lying to the northwest and southeast and inferred to be on the limbs of the fold. (See p. 27)

Southeast of the Weeksboro–Lunksoos Lake anticline, the folds in rocks of Ordovician and Silurian age appear to be as tight as those in the Grand Pitch of Cambrian(?) age, but minor folds and cross folds are not as abundant. From northwest to southeast the sequence appears to be as follows: A synclinorium in which the Allsbury Formation is preserved, an anticlinorium in which the Mattawamkeag Formation is exposed, and a synclinorium in which the rocks of Island Falls are preserved. The anticlinorium is roughly outlined by conglomerate lenses of Silurian age, and the strata in this region nearly everywhere dip vertically. In the southeastern part of the quadrangle the beds are commonly overturned as much as 15°–25° from vertical.

The simplest fold in the Island Falls quadrangle is the Wadleigh Bog syncline, where strata of Silurian and Devonian age (pre-Acadian) have relatively gentle dips of 55°–70°, and minor folds are absent or few. The strata in the Wadleigh Bog syncline are dominantly pelitic, and the relative openness of the fold, compared with folds in the southeastern part of the quadrangle, suggests an overall northwestward decrease in the intensity of deformation in the Island Falls quadrangle during the Acadian orogeny.

TRANSVERSE FOLD AT CRYSTAL LAKE AND WEBSTER BROOK

A northwest-plunging anticline is inferred from strike directions in the vicinity of Crystal Lake and Webster Brook. This inference is supported by aeromagnetic data which show a northwest trend in the vicinity of Webster Brook and a sharp change in strike about 1½ miles west of Crystal Lake. The data indicate that the rocks probably again change strike to the north or northwest on the east side of Crystal Lake and then gradually swing northeast. At Webster Brook the magnetic anomaly coincides with outcrops of graywacke and gray slate of the Mattawamkeag Formation. Conglomerate lenses to the west are relatively nonmagnetic. At Crystal Lake, however, the aeromagnetic anomaly appears to coincide partly with conglomerate.

The transverse folding is unusual in a region in which northeast-trending folds predominate. The Crystal Lake area was probably uplifted as well as compressed during folding; therefore, an intrusive plug or stock may underlie the Crystal Lake area.

MINOR FOLDS

Folds whose wavelengths and amplitudes range from a few inches to 20 feet are abundant in the Grand Pitch Formation, and they occur also in the rocks southeast of Mount Chase ridge.

Most of the folds in the southeast probably formed simultaneously with the major folds, but few are of the drag-fold type. Most have nearly equally inclined limbs and are locally of the chevron type. These folds do not appear to bear the same relation to the major folds that drag folds do. They are concentrated near the axial planes of the major folds, and nearly all the folds have very steep plunges. Most major folds, on the other hand, plunge at relatively gentle angles as deduced primarily from tracing of black slate zones by the electromagnetic method. Some belts of black slate were traced as far as 10 miles. Zones of this length are unlikely if all major folds plunge very steeply.

In a few places in the southeastern part of the quadrangle, especially near the town of Island Falls, there are younger minor folds that affect both bedding and cleavage. At Island Falls some of these are asymmetric, have south-striking axes, and appear to be related to the intrusion of the large stock that crops out in the adjacent Smyrna Mills quadrangle. Other minor folds strike east-northeast and are present at intervals throughout the southeast part of the quadrangle, far removed from any known intrusive mass. These folds are very weakly developed, but their axes appear to be nearly parallel to east-trending cross cleavage that is fairly well defined locally.

The minor folds in the Grand Pitch were formed both before and after the cleavage. Like the minor folds southeast of Mount Chase, these folds plunge very steeply. Their detailed relations to major folds have not been determined.

FAULTS

FAULT AT BASTON AND EAST HASTINGS BROOKS

A northwest-striking fault is indicated near Baston Brook east of Mattawamkeag Hill. The fault plane was not directly observed, but a line of springs east of Baston Brook presumably marks the fault trace. The fault is probably the principal cause of the sharp offset of the belt of volcanic strata of the Mount Chase area; however, electromagnetic data suggest that the offset is due partly to folding. At East Hastings Brook the fault either swings north or intersects a north- and northeast-trending fault that cuts through Shoaler Mountain. The course of East Hastings Brook changes from south to southwest at the fault line, where brecciated rocks of the Grand Pitch Formation are in fault contact with the Allsbury Formation. This juxtaposition indicates that the vertical displacement may be as much as several thousand feet.

North of Mattawamkeag Hill the fault is presumed to change strike to west and finally southwest, but its presence here is problematical. The inference that a fault is present in this area is based entirely on the occurrence of sheared and brecciated rock. Intensely sheared rock crops out along the north slope of Mattawamkeag Hill, and northwest-striking joints adjacent to the sheared rock support the inference that the fault trends northwest between Knowles Corner and Mattawamkeag Hill. Near Rockabema Lake, the fault zone trends northeast (locally north) and probably comprises three separate faults. One fault is on or adjacent to a small island at the southeast end of the lake. The island is elongated, trending north, and shear zones on the island also trend north. The rock consists entirely of breccia. In places the breccia consists of fragments of quartzite and slate derived from the Grand Pitch Formation; in other places the breccia consists almost entirely of fragments of Rockabema Quartz Diorite. The whole mass resembles a coarse conglomerate. Zones of slate are intensely pyritized locally, and the slate weathers to form yellow and black gossaniferous outcrops. A second northeast-trending fault is believed to pass about 1,000 feet southeast of the "island" fault and separates Rockabema Quartz Diorite from slate of the Grand Pitch Formation. This second fault is inferred solely from the occurrence of intensely sheared rock. A possible third fault passes about 1,000 feet southeast of this fault and separates sheared slate of the Grand Pitch Formation from sheared volcanic rocks of the Mount Chase area. Its presence is inferred from rocks in Atwell Brook, where several feet of mylonite or intensely sheared fine-grained tuff is exposed. Rocks in this area are iron stained and locally pyritized. Southwest of Rockabema Lake the three faults are presumed to merge into a single fault, but outcrops are rare in this area and several faults could be present. Southwest of Pleasant Lake a single fault separates the Grand Pitch Formation from volcanic rocks of the Mount Chase area, and several feet of mylonite is exposed where the fault crosses a tributary of West Creek in T. 6, R. 6 W.

FAULT AT LANE BROOK

Fossil localities 1 and 2 (pl. 1) are presumed to be separated by a fault; locality 2, although in a stratigraphically lower position than locality 1, yields fossils of younger age. (See p. 17.) There is no other evidence of a fault in the near vicinity. The location and the strike of the fault, therefore, are problematical.

POSSIBLE FAULT ALONG THE MOUNT CHASE FRONT

Several lines of evidence suggest that the contact between the Allsbury Formation and the volcanic rocks of the Mount Chase area may be a fault contact. Near the contact the strata are intensely sheared and brecciated. Locally, they are intensely pyritized, and, between Kilgore School and the Mattawamkeag River valley, they show a few faint stains of secondary copper minerals. Southwest of Mount Chase in the Shin Pond quadrangle, the Allsbury Formation is separated from the volcanic rocks of the Mount Chase area by a thick zone of conglomerate, which is not present along the contact of the Allsbury with the volcanic rock in the Island Falls quadrangle. The conglomerate may be highly discontinuous and may not have been deposited here; however, its absence along the Mount Chase front may be due to elimination by faulting.

POSSIBLE FAULT AT KILGORE KNOLL

The belt of conductive slate and chert and associated greenstone of Ordovician age at Kilgore Knoll is surrounded by the Allsbury Formation of Early Silurian age. On the northwest side the belt appears to parallel a conductive zone in the Allsbury Formation, and the Ordovician-Silurian contact is probably normal. On the southeast side however, the greenstone is flanked by nonconductive sheared slate of the Allsbury; this contact may be a fault, as inferred on plate 1. The inferred fault could account for the abrupt disappearance of Ordovician strata to the northeast and southwest.

CLEAVAGE AND ITS RELATION TO STRUCTURE

Cleavage is conspicuous in most of the strata in the Island Falls quadrangle. The average strike is north-northeast, and the dip is vertical or nearly so except in the area southeast of a line extending roughly from the intersection of Crystal Brook and Crystal Road through a point about midway between Stair Falls and Warren Falls. In this area the cleavage dips 55°–85° NW. Where good exposures are available it is apparent that the cleavage is not parallel to the axial planes of the major folds. Near Warren Falls, for example, top directions in graded beds of graywacke define a large syncline that plunges steeply to the northeast. In this area, cleavage strikes consistently N. 10°–30° E., which is more northerly than the strike of the bedding on either limb of the syncline. The cleavage, therefore, is younger than the major folds. According to M. P. Billings (oral commun., 1961), the cleavage probably formed under the same forces that produced the major folds, but after a slight shift in the applied direction. Relations between folds and cleavage in the nearby Maple and Hovey Mountains area of Aroostook County were described by Pavlides (1962, p. 30–31).

METAMORPHISM

EFFECTS ON MINERALOGY

The Island Falls quadrangle lies in a regionally metamorphosed area that corresponds to the chlorite zone (Harker, 1956). The rocks have been intensely deformed by mechanical forces operating at low temperatures.

The chief minerals of the sedimentary rocks are sericite, quartz, and chlorite. The sericite and chlorite are apparently both authigenic, but there has been no recrystallization of detrital quartz. In many slates, for example, cleavage planes are outlined by tiny grains of sericite and chlorite, and bedding planes by grains of detrital quartz. The black slates contain abundant carbon, none of which has attained the crystal structure of graphite.

The pelitic sediments along the east border of the quadrangle near the De Lette and Pleasant Lake plutons (p. 18) have been baked to form hornfels rims that partly surround the intrusive igneous masses. Recrystallization during thermal metamorphism has obliterated slaty cleavage but has not affected bedding, which in places has actually been accentuated by color changes during metamorphism. On May Mountain, adjacent to the Pleasant Lake pluton, slate and sandstone contain quartz, biotite, tremolite, and actinolite. In some beds biotite is the principal constituent; in other beds in the same outcrop, biotite is sparse and actinolite is the principal constituent. These differences are not related to the distance of the bed from the intrusive mass but are due to original differences in the chemistry of individual beds.

Some of the hornfels on May Mountain contains as much as 20 percent pyrrhotite, which gives rise to an aeromagnetic anomaly (pl. 1). The hornfels on De Lette Ridge was not examined in thin section, but the grade of thermal metamorphism is probably about the same as that on May Mountain. The metamorphosed rocks, however, are confined to a much narrower belt.

No hornfels was observed around the stocks of quartz diorite near Rockabema Lake or East Hastings Brook. Thin sections of both quartzite and slate of the Grand Pitch Formation taken only a few feet from contacts with quartz diorite show the principal constituents to be quartz, sericite or muscovite, and chlorite. The lack of visible contact-metamorphic minerals in the Grand Pitch is probably due to two factors: (1) the rocks are rich in quartz, so that garnet, biotite, and other metamorphic minerals would not have tended to form in great abundance when the stocks were intruded, and (2) during subsequent regional metamorphism some metamorphic minerals—for example, biotite and garnet—probably reverted to chlorite.

ORIGIN OF ALBITE IN THE VOLCANIC ROCKS

Plagioclase breaks down to form albite and epidote or zoisite in rocks subjected to low-grade regional metamorphism, as is well known. The problem in the Island Falls quadrangle is to determine whether the albite in the volcanic rocks resulted from dynamometamorphism or alkali metasomatism, or both.

Remnants of plagioclase as calcic as labradorite in some of the diabase in the Island Falls quadrangle eliminate the possibility that the sodic plagioclase was an original constituent. The albite was unquestionably formed after the rocks were emplaced. Two lines of evidence suggest strongly that some Na_2O was introduced: (1) plagioclase crystals in the rocks are characterized by mottled extinctions, which are universally typical of replaced crystals, and (2) most of the basaltic rocks are nonschistose and retain their original ophitic or basaltic texture. Gilluly (1935, p. 342) pointed out, regarding the origin of albite in the diabasic-textured greenstones of the Baker quadrangle, Oregon:

> The fact that, under low temperature conditions of rock formation, it is the rule for plagioclase to break down into albite plus some other minerals, is in itself suggestive that regional metamorphism may sometimes bring about the albitization of considerable rock bodies. On the whole, however, it is the habit of saussuritization to produce epidote or zoisite in the altered feldspar concomitantly with the albite. The retention of the ophitic texture of many albite diabases is evidence that any chemical changes they have undergone have been essentially metasomatic, so that albite has been introduced in equivalent volume to the anorthite expelled.

The almost universal association of spilitic rocks with a eugeosynclinal or marine environment has been considered by some investigators to be a vital clue to origin. Daly (1914, p. 338–340) was one of the first to suggest that spilites are a product of their sodium-rich submarine environment: he considered the albitization due to eruption through wet sediments. The volcanic strata in the Island Falls quadrangle are probably in large part, if not entirely, of submarine origin. They are overlain and underlain by marine strata, and they may well have been saturated throughout with marine water representing a tremendous reservoir of sodium ions. Recently Orville (1963, p. 201–237) and other investigators (in Orville, 1963) showed experimentally that alkali ions transfer readily in the vapor–alkalic feldspar system. Orville (1963, p. 236) concluded: "It is quite certain that connate waters, whatever their original alkali ratio may be, will approach equilibrium with alkali-bearing crystalline phases at comparatively low temperature * * *." Dickinson (1962) described metasomatic quartz keratophyre formed from rhyodacitic ash-fall tuff associated with marine sediments in central Oregon. According to Dickinson (1962, p. 251), none of the Jurassic rocks associated with the quartz keratophyre have mineral assemblages indicative of the greenschist facies. The original tuff structure is well preserved, and the rock was apparently first zeolitized and then albitized. Dickinson (1962, p. 265) concluded that the tuff was converted to quartz keratophyre probably prior to the Late Jurassic or Early Cretaceous folding. He pointed out that the nearest and perhaps the only source of reactive fluids rich in sodium apparently was connate pore waters and adsorbed aqueous films that must have been expressed from associated and underlying marine mudstones by compaction.

The evidence as to the origin of the albite in the volcanic rocks of the Island Falls quadrangle is not conclusive, but in view of all the data, the most probable explanation is that the albite originated, in part at least, from alkali metasomatism.

SUMMARY OF GEOLOGIC EVENTS

1. The Grand Pitch Formation of Cambrian(?) age was deposited in an eugeosyncline in which a reducing environment prevailed.

2. The strata of the Grand Pitch Formation were folded and exposed to erosion.

3. The volcanic rocks of the Shin Brook Formation and the Mount Chase area were deposited on the eroded surface of the Grand Pitch Formation, probably during early Middle Ordovician time. (Possibly simultaneously with the volcanic eruptions, the Mattawamkeag Formation, consisting of feldspar-rich graywacke and slate, was deposited southeast of the centers of volcanic activity. Because of a lack of fossil dating of the Mattawamkeag, and uncertain stratigraphic relations, the formation is excluded from this sequence.)

4. A large anticline or anticlinorium was formed in the northwest part of the quadrangle at or near the close of the Ordovician Period, and a large stock of quartz diorite was intruded near Rockabema and Pleasant Lakes.

5. During earliest Silurian time, erosion and denudation of the anticline gave rise to deposits of conglomerate in the extreme northwest and southeast parts of the quadrangle.

6. Shale and graywacke of the Allsbury Formation, and silty limestone, shale, and sandstone of the rocks of Island Falls were then deposited in the southeast part of the quadrangle; siltstone and slate associated with coral-reef detritus were deposited in the northwest part. The coral-reef detritus apparently was derived from reefs that formed on topographically high parts of the old anticline.

7. The Seboomook Formation of Devonian age was deposited.

8. The eugeosyncline, which had persisted intermittently from earliest Paleozoic time, was intensely buckled during the Acadian orogeny. This orogeny closed the eugeosynclinal cycle and was followed by the intrusion of granitic stocks of post-Early Devonian and pre-Late Devonian age.

9. The post-intrusion pre-Pleistocene record is lost in the Island Falls area. The region may have stood as a landmass since the Devonian.

ECONOMIC GEOLOGY

Mineral deposits of commercial value are unknown in the Island Falls quadrangle with the exception of extensive deposits of sand and gravel. Limestone in the vicinity of Bradford Brook was used by early settlers for fertilizer and lime plaster. It is still potentially valuable for such uses. The limestone consists locally of pure calcite, but the deposit is thin and limited in area. Small amounts of asbestos and talc occur in a few shear zones in the volcanic rocks of the Mount Chase area. The shear zones are only a few inches thick, and none of the material is considered to be of commercial value.

Finely disseminated pyrrhotite is found in hornfels at May Mountain. The pyrrhotite is in the form of tiny grains that range in diameter from about 0.01 mm to slightly over 0.1 mm. In some outcrops the pyrrhotite makes up as much as 20 percent of the volume of the hornfels, and presumably causes an aeromagnetic anomaly that partly surrounds the stock at Island Falls. In places there may be sufficient pyrrhotite or other minerals in the hornfels rim to warrant detailed prospecting.

The most promising area for metallic mineral deposits is the south flank of the Rockabema intrusive mass at Rockabema Lake, where there are several fault zones containing pyrite and abundant iron oxides.

Sand and gravel of glacial origin are abundant in the Island Falls quadrangle. The thickest and most extensive deposits occur east of Patten near Webster and Lyman Brooks. The sand and gravel is mostly well-stratified glacial outwash. Eskers flank Lyman Brook and also the West Branch Mattawamkeag River. The eskers are extensively quarried for gravel, and at the present rate of consumption, represent ample reserves for many years. Other large eskers not currently quarried for sand and gravel occur between Crystal Lake and Crystal Brook, north of Crystal Lake along Houston Brook, along the northeast shore of Pleasant Lake, and along West Hastings Brook north of the Lane Brook tote road (International Paper Co. road). A small esker crops out east of Lane Brook Meadows north of elevation 862 feet; it could be a convenient source of gravel for the improvement of the Lane Brook tote road.

GEOPHYSICAL INVESTIGATIONS

SLINGRAM METHOD

The slingram or "loop frame" method of electromagnetic measurement (Frischknecht, 1959) was used in the Island Falls quadrangle. Of all electromagnetic prospecting methods in current use, the slingram method and the inline moving-source dip-angle method are the most suitable for reconnaissance work. The dip-angle method requires a crew of only two men, the equipment is somewhat simpler than for the slingram method, and no connection is required between the receiver and the transmitter. However, the slingram method was chosen over the dip-angle method because it is at least as economical to use in unsurveyed areas for reconnaissance work, and for the same frequency it is better suited for defining weak conductors. In addition, the slingram method is responsive to conductors striking normal to the traverse.

A simplified sketch of the equipment used during the summer of 1961 is shown in figure 7. The coils are moved together at a fixed separation of about 100–300 feet. Of the possible coil orientations that are practical for ordinary slingram equipment, the horizontal coplanar arrangement is the most sensitive and the most commonly used.

The equipment shown in figure 7 functions as follows: The primary magnetic field from the transmitting loop induces eddy currents in conductive rocks. These eddy currents give rise to a secondary magnetic field. A voltage proportional to the vector sum of the primary and secondary fields is induced in the receiving coil. In general, at the receiving coil the secondary field is weaker and is not in phase with the primary field. The ratiometer measures the inphase and out-of-phase ratios of the receiving-coil voltage compared with a reference voltage obtained from a small coil attached to the main transmitting coil and fed to the ratiometer by a cable. In the ratiometer the RC networks develop voltages across two potentiometers which are 90° out of phase with respect to each other. To make a measurement the sliders on the potentiometers are adjusted until the vector sum of the voltage between the sliders is equal in magnitude and phase to the voltage from the receiving coil; this point is indicated by a null in the tone from the headphones. Readings are taken from dials connected to the shafts of the two potentiometers.

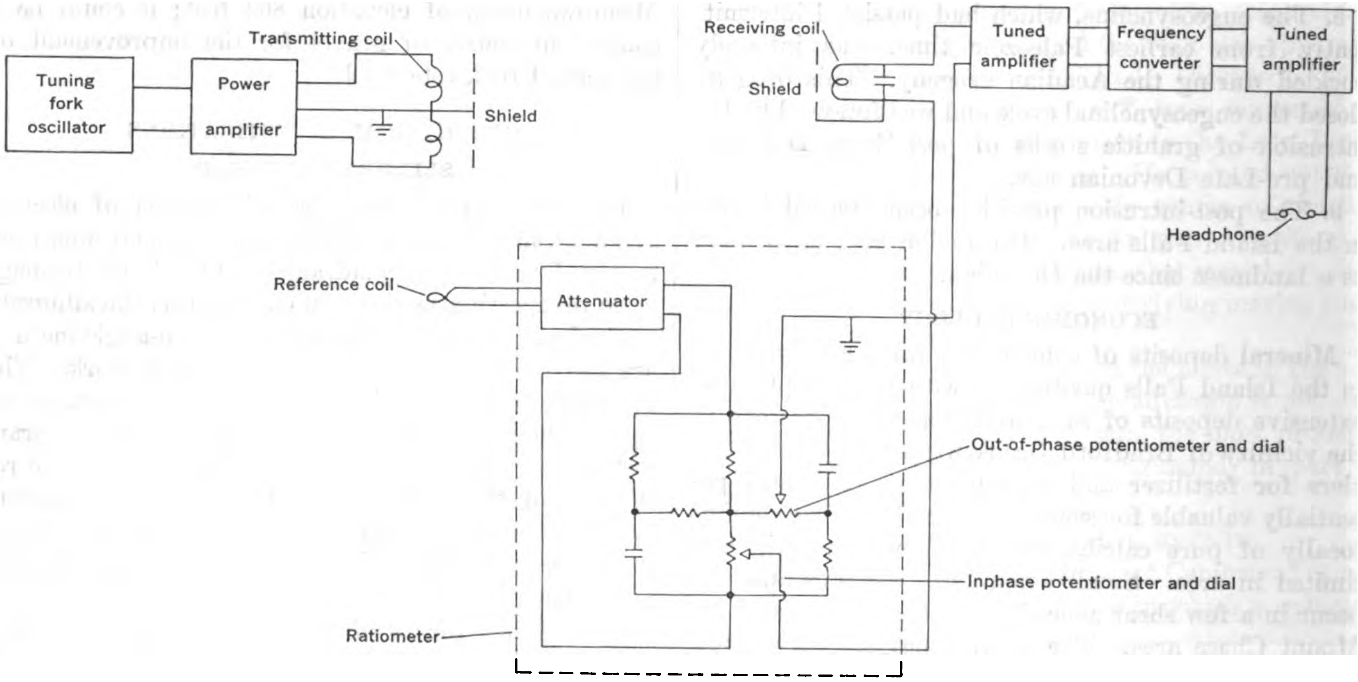


FIGURE 7.—Circuit layout, slingram apparatus.

Before measurements are made, the attenuator and other zero controls (not shown in the figure) are adjusted so that the inphase and out-of-phase readings over nonconducting earth are 100 percent and 0 percent, respectively. Thus the ratio of the mutual coupling between two coils in the presence of conducting bodies to the mutual coupling between the coils in free space is measured. If the spacing of the coils is changed, or if the coil orientation is changed from coplanar to coaxial or vice versa, the attenuator must be reset, because the magnitude of the mutual coupling in free space is changed.

The magnitude of an anomaly depends upon the product of the frequency of the transmitter current, the conductivity, as well as the size, shape, and depth of burial of the conductor (Ward, 1959). For relatively small values of the product of frequency and conductivity, the out-of-phase component is larger than the inphase component, and both become larger as the frequency or conductivity, or both, increase. As the product of frequency and conductivity increases to a relatively large value, the out-of-phase component passes through a maximum and then becomes smaller, while the inphase component becomes larger, approaching an asymptotic value for very large products. A somewhat higher frequency than is usual in prospecting for ore was used in the Island Falls quadrangle in order to detect weak conductors. There are practical limits to how high a frequency should be used; in particular, thick conductive glacial drift may tend to limit penetration of high-frequency fields and may also cause local anomalies owing to variations within the glacial drift.

EQUIPMENT AND FIELD TECHNIQUES

A ratiometer, power supply, and transmitting and receiving coils constructed by the Swedish Geological Survey, and an amplifier constructed by the U.S. Geological Survey, were used during the summer of 1959. This equipment operated at 3,600 cps (cycles per second). For the 1960 field season new equipment intended for operation at 2,000 or 8,000 cps was constructed by the U.S. Geological Survey. Operation at 8,000 cps was not satisfactory because the self-resonant frequency of the receiving coil was only slightly greater than 8,000 cps. At 2,000 cps, the zero settings of this equipment drifted somewhat excessively, primarily because of frequency changes in the commercial LC oscillator used to drive the power amplifier. For the 1961 field season the equipment was rebuilt, and the LC oscillator was replaced by a tuning-fork oscillator, eliminating most of the drift in the zero settings. The 1961 equipment drifted slightly with changes in temperature, and small changes in zero level or "tares" sometimes occurred between traverses. The tares may have been caused by shifting of the windings within the receiving coil when the coil was jarred by rough handling.

›rable conditions, the relative accuracy
ent stations in the out-of-phase compo-
ıt 0.5–1.0 percent in 1959 and 1960 and
rcent in 1961. Differences in elevation
ls or inexact coil spacings generally cause
nphase component that are greater than
tal inaccuracies. Interference from 60-
s near powerlines and some telephone
t impossible to obtain a sharp null, so
ı near powerlines may be in error by sev-
Harmonic interference was almost negli-
anch lines serving only a few farms but
ıounced from main lines.
ments near powerlines, secondary cur-
in the loop formed by grounded over-
ıd the earth may cause anomalies. The
lines are particularly effective because
wire that is grounded at every guy and
During traverses parallel to an REA
long a road, a negative anomaly of —10
nt is observed in the out-of-phase com-
anomaly varies with distance from the
ance from grounding points, and other
efore little reliance can be placed on
made less than 50–100 feet from power-

"regular" traverses in the Island Falls
standardized technique was employed
tal coplanar coils, a spacing of 200 feet,
interval of 100 feet. Experimental tra-
ade using other coil spacings and orienta-
st areas underlain by conductive rocks,
rift was less than 50 feet thick, so that
; of 200 feet or less gave adequate depth
r weak conductors. To provide a satis-
e of the shape of an anomaly, the station
ld be no more than one half the coil
a 100-foot spacing requires a station
feet and is a rather slow method. A coil
er than 200 feet might have been de-
eater range in areas of thick glacial drift
me. However, working with long coil
wkward, and in dense woods 200 feet is
it for voice communication between re-
ransmitting stations.
ular traverses were made using a fre-
ıer 2,000 or 3,600 cps. Two experimental
ved that measurement at 8,000 cps would
sible in much of the quadrangle since, in
he glacial drift is thin and has a rela-
istivity of 500–10,000 ohm-meters as measured by L. A. Anderson of the U.S. Geological Survey. However, reliable 8,000-cps equipment was not available until 1961, too late for efficient utilization in this study.

ation Administration.

Traverses were run mainly along roads, trails, town lines, or the edge of open fields, but where necessary, they were made along compass lines, entailing some brush cutting. Roads and trails have several disadvantages for traverses. They are usually not ideally located and do not cross the strata at a favorable angle with respect to the strike. Also, many roads and trails are so winding that the straight-line distance between coils is too short, even though the reference cable is pulled taut. Large errors in the inphase component result from traverses along winding roads, but the out-of-phase component is not seriously affected.

The measurements were made by a crew of three—one man carried the transmitting coil and transmitter, one carried the receiving coil, and the operator carried the ratiometer. The man carrying the receiving coil marked each new station with surveyor's flagging tape. Distances were chained off using marks on the reference cable.

On a good road, readings can be made at 100-foot intervals at a rate of about 6,000–7,000 feet per hour. In thick woods and bogs progress may be slowed to 2,000–3,000 feet per hour. Two men can cut a suitable line through open woods at a rate of perhaps 3,000 feet per hour; in thick woods their progress is slowed to 1,500–2,000 feet per hour. About 150 man days was required to complete 105 miles of electromagnetic traverses in the summer of 1961.

INTERPRETATION OF ELECTROMAGNETIC PROFILES

Results of electromagnetic studies, like those of many other types of geophysical investigations, are interpreted by comparison with catalogs of reference curves for different geologic situations. Because of mathematical difficulties, reference curves for electromagnetic methods are usually obtained from actual measurements over scale models rather than from calculations.

If a conductor is fairly homogeneous and has a reasonably simple shape, such parameters as thickness, depth of burial, dip, strike, and conductivity can be estimated with fair accuracy from the observed anomaly, provided suitable reference curves are available. If the conductor is a thin bed, its thickness and conductivity cannot be determined, but their product can. Most of the anomalies in the Island Falls quadrangle are complicated, and quantitative interpretation is difficult or impossible. Generally, only the position of the conductor or conductive belt and its total thickness or width were determined for this study. Where possible the direction of dip was predicted. The magnitudes of anomalies, which depend on both the conductivity and thickness of the conductors, were considered in correlating anomalies between traverses.

Many conductors in the Island Falls quadrangle can be approximately represented in a scale model by a single thin conductive sheet dipping almost vertically. The shapes of the anomalies over these conductors resemble the model curves (Frischknecht and Mangan, 1960) in figure 8. The conductor lies directly under the minimums and the separation between the two points at which the out-of-phase curve goes through zero (and also the two points at which the inphase curve goes through 100 percent) is approximately equal to the coil spacing. If the conductor strikes normal to the line of traverse, the separation between the subsidiary highs is only slightly greater than the coil spacing, whereas if the conductor strikes at an acute angle to the line of traverses, the distance between subsidiary highs is considerably greater than the coil spacing.

If the separation between the two 0 percent points or the two 100 percent points on the anomaly is much greater than the coil separation, the conductor has an appreciable thickness, or more than one thin conductor is present. The edges of the thick conductor or the positions of the outermost of the thin conductors are at distances approximately equal to one-half the coil spacing, measured in from the zero points. In practice the thickness of a conductor may be determined to an accuracy of about 10 percent of the coil spacing.

If the dip is not vertical, the curve is asymmetric, having one subsidiary high greater than the other. When the traverse is normal to the strike, the dip is in the direction of the greater of the two subsidiary highs. If the conductor strikes at an acute angle to the traverse, the situation is more complicated. If the inphase component is being considered, the greater of the subsidiary highs gives the direction of dip, but if the out-of-phase component is being considered the direction of dip may be toward the smaller of the two highs.

If a belt of thin conductors is traversed at an acute angle, the anomaly may be predominantly or entirely positive, or greater than 100 percent, whereas a massive conductor having the same total width as that of the belt of thin conductors and traversed at the same angle yields a negative anomaly in the center and two

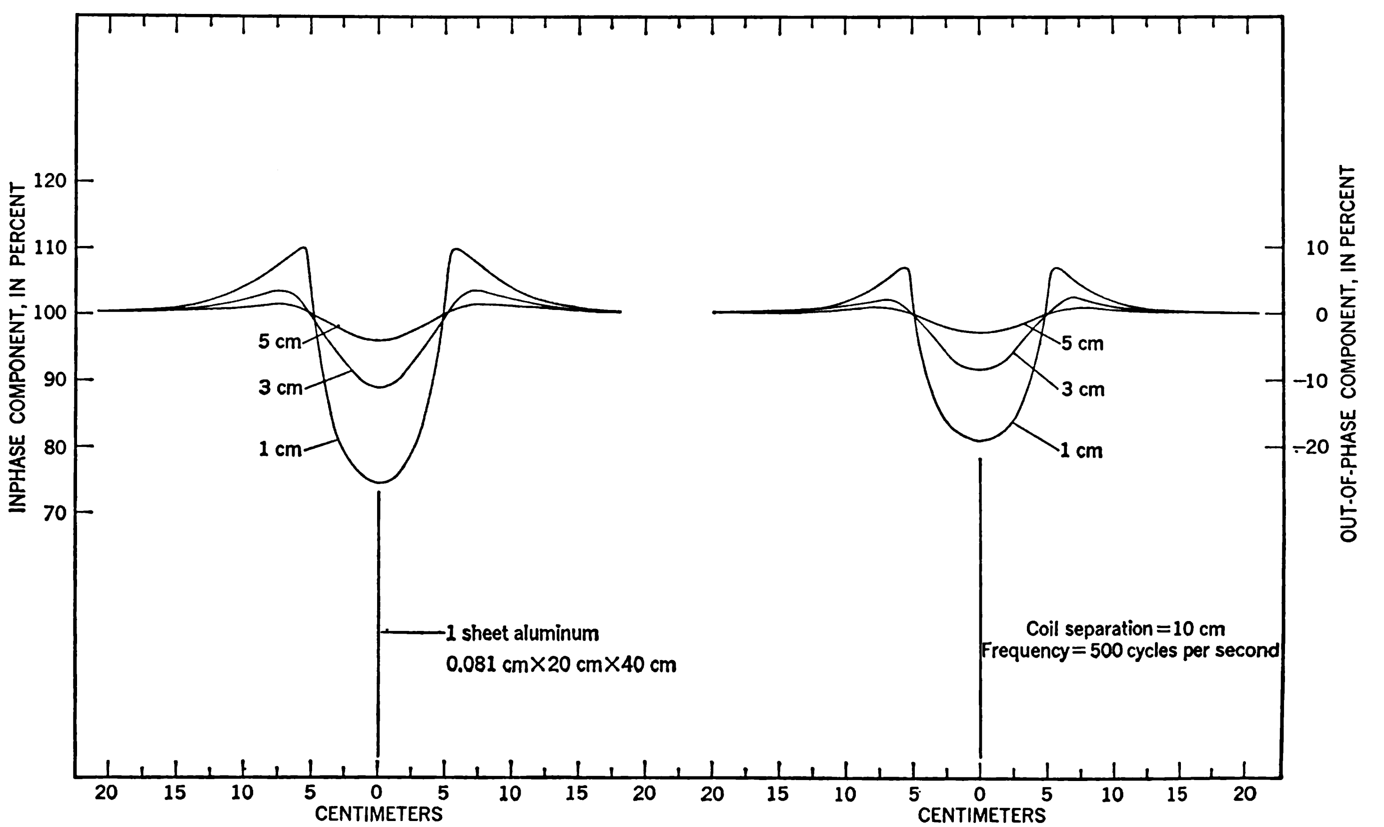


FIGURE 8.—Model curves of slingram method.

large positive anomalies on either side. This effect is produced because the anomaly for a traverse at an acute angle to the strike over a single thin conductor may have a larger area under the positive part of the curve than under the negative part. The effects of a series of thin conductors are cumulative, so that the positive parts of the anomalies offset the negative parts. This effect has also been noted when the dip-angle method is used for traverses over schistose conductors (Swanson, 1960).

The locations of all the electromagnetic traverses were plotted on an index map (pl. 2).

The out-of-phase component for part or all of most traverses is shown. No significant anomalies occur along any traverses that were not plotted, except for T–29. In accord with common practice, anomalies are plotted so that negative anomalies appear as highs and positive anomalies as lows. No attempt was made to correct for drift or tares in the zero setting of the equipment; therefore, differences in the apparent zero level of the profiles are not significant. The profiles made at 3,600 cps are so designated; the remainder were made at 2,000 cps. Anomalous zones were correlated between traverses, and inferred conductors or conductive belts were drawn on the geologic map (pl. 1).

Because the out-of-phase component is usually larger and is not subject to errors in coil spacing, it was used almost exclusively in delineating conductive zones. In only a few circumstances does the inphase component yield better information. There is a remote possibility that some very good conductors at depth, which cause insignificant out-of-phase anomalies, were missed because care was not always taken to obtain accurate readings for the inphase component. In most areas, out-of-phase anomalies as small as 3–5 percent were deemed significant.

The model curves for 1-cm depth (fig. 8) resemble rather closely the anomaly which occurs 3,500 feet east of the west end of T–34. Minimum values of the inphase component are 64 percent for the field anomaly (not shown) and 74.5 percent for the model anomaly; maximum values of the out-of-phase component are 25 percent for the field anomaly and 19 percent for the model anomaly. The depth of the glacial till in this area is probably less than one-tenth of the coil spacing, and the anomaly indicates that the conductive bed is dipping slightly. Both of these factors tend to increase the field anomaly over the model anomaly. The equivalent depth extent of the model is only 400 feet, but the anomalies would be little different for a sheet of infinite horizontal and depth extent. The conductance of the model is 2.86×10^6 mhos. If the proper scaling relationships are used, and the model is assumed to represent the field conductor accurately, the conductance of the field conductor is 11.75 mhos. This could correspond to a bed 5 feet thick having a resistivity of 0.130 ohm-meter or a bed 20 feet thick having a resistivity of 0.519 ohm-meter. The field curves indicate that the conductor is not more than 20–30 feet thick, so the resistivity (parallel to bedding) is not more than about 0.8 ohm-meter. The ratio of the inphase to out-of-phase components for this conductor is greater than for most conductors in the Island Falls quadrangle. By comparison with other model data, the conductance of most of the conductors is estimated to be in the the range of 1–10 mhos.

GRAND PITCH FORMATION

In the Island Falls quadrangle both the Grand Pitch Formation and the Allsbury Formation bear conductive strata. In general, anomalies from the Grand Pitch are more complex than those from the Allsbury. Isolated anomalies are less common and positive anomalies are more common, even for traverses which are normal to the regional strike. The latter observation suggests that there may be considerable local folding in the black slates which does not parallel the regional strike. In detail, anomalies cannot be correlated between traverses. Although there could be lithologic reasons for it, the greater complexity of anomalies from the Grand Pitch is probably a reflection of more complex deformation.

Although individual features in the Grand Pitch Formation cannot be correlated between traverses, belts of anomalies can be traced. One major belt parallels the Silurian rocks in the northwest part of the quadrangle, another belt or series of belts occurs south of Frost and Adams Ridge, and a third belt of relatively strong conductors lies southeast of Rockabema Lake. Minor conductors occur 1½ miles northwest of Knowles Corner and 1½ miles north of Pleasant Lake.

The axis of the Weeksboro-Lunksoos Lake anticline separates the belts of conductors into two groups which probably represent younger rocks on the limbs of the anticline. If so, the belt of conductive rocks southeast of Rockabema Lake is a continuation of one of the belts defined south of Frost and Adams Ridge.

North of the Lane Brook tote road, much of the entire section of the Grand Pitch contains conductive rocks; it is therefore easy to locate the contact between the Grand Pitch and other rocks by electromagnetic measurements. The same is true for the belt of Grand Pitch southeast of Rockabema Lake.

ALLSBURY FORMATION AND ROCKS AT KILGORE KNOLL

In the Allsbury Formation, three narrow prominent belts of conductors were traced for about 10 miles. Other conductors were traced for several miles. The conductivity or thickness, or both, and the number of conductors within each belt vary considerably along strike. The system of conductors is most extensive in the vicinity of the Allsbury and Clark Roads. South and west towards the Sherman and Shin Pond quadrangles, the conductors become less prominent and some pinch out. Along T–100, just south of the Island Falls boundary, all the anomalies represent isolated thin beds.

A series of closely spaced anomalies which does not carry through to adjacent traverses occurs on T–94. These anomalies may represent a repetition of the same bed; however, they are shown as isolated units, because the nature of the structure cannot be deduced. South from Myrick School, the most prominent belt of conductors in the Allsbury Formation bifurcates into belts which continue on toward the Sherman quadrangle. Other bifurcations are less pronounced.

Northeastward from the Allsbury Road, the conductors tend to converge and to weaken and pinch out. The few conductors in the area about 2 miles northwest of Batesville between Halls Corner and Mill Brook are very weak. Near Batesville several anomalies, some of them fairly large, cannot be logically connected. North of Kilgore School, the belt of conductors near the contact with the volcanic rocks of the Mount Chase area becomes much more prominent. Farther east, about 1 mile north of Batesville at Kilgore Knoll, a good conductor is present in slates and black cherts of Ordovician age. The conductor extends from immediately northwest of the intersection of Mill and Bradford Brooks almost to the West Branch Mattawamkeag River; inphase readings were as low as 33 percent (67 percent anomaly), and corresponding out-of-phase readings were 11 percent. For this ratio of the inphase to the out-of-phase component, the conductor would be classified as a good conductor in terms of measurements at 2,000 cps.

In the salient of the Allsbury Formation at Baston Brook, traverses T–20 through T–25 reveal the presence of large amounts of conductive strata. On T–22 and T–23 and on part of T–20, the data indicate that most of the conductors strike normal to the contact with the volcanic rocks of the Mount Chase area, thus suggesting a fault-contact. However, for a distance of about 1,700 feet along T–20, from a point 1,000 feet northwest of the intersection with T–21, the anomaly is predominantly a positive one, indicating that in this vicinity the conductors tend to parallel the contact. This in turn indicates that the beds locally have been folded to parallel the contact and that the salient is due in part to folding. The generally complex anomalies in the salient suggest a complicated pattern of folds.

EXPERIMENTAL TRAVERSES

Two experimental traverses were made over areas containing weak conductors, at frequencies of 2,000 and 8,000 cps, with horizontal coplanar orientation of coils. The coil stations were almost the same for both frequencies, and the coil spacings were measured with reasonable accuracy since the traverses were along straight roads.

On traverse T–59X (fig. 9) a weak conductor was mapped which intersects the traverses at about 5,200 feet east, and a zone containing three or four conductors was mapped between about 1,100 feet east and 2,000 feet east. The conductors in the latter zone intersect the traverse at a fairly sharp angle, as indicated by the relative magnitudes of the positives and negatives. On traverse T–73X (fig. 10) a minor conductor was mapped at about 4,800 feet east, and a narrow zone, probably containing two conductors, was mapped between about 700 feet east and 1,100 feet east. The anomaly at 4,800 feet east is predominantly a low, indicating that locally the conductor strikes at an acute angle to the traverse, even though, as determined by correlation with adjacent traverses, regionally the conductor is at an angle of perhaps 60° with respect to the traverse. Several minor conductors, not deemed significant, occur along both traverses.

The out-of-phase curves for the two frequencies follow each other rather closely except that the anomalies at 8,000 cps are two to four times as large as those at 2,000 cps. For the larger anomalies, the inphase curves are similar but differ considerably in detail. Perhaps some of the smaller features on the 8,000-cps profiles, which are not shown on the geologic map, could be traced by means of closely spaced traverses. However, in this part of the quadrangle a sufficient number of conductors for mapping purposes were found with 2,000-cps measurement. In other parts of the quadrangle, where mappable units were not found with 2,000-cps measurements, useful results might have been obtained at 8,000 cps.

On T–85X (fig. 11) measurements were made at 2,000 and 8,000 cps using horizontal coplanar, vertical coaxial, and vertical coplanar coil arrangements. A faulty switch in the equipment prevented the recording of some of the readings for the 8,000-cps vertical coaxial curves. The conductive zone extends from about 350 feet east to 850 feet east. The edges of the

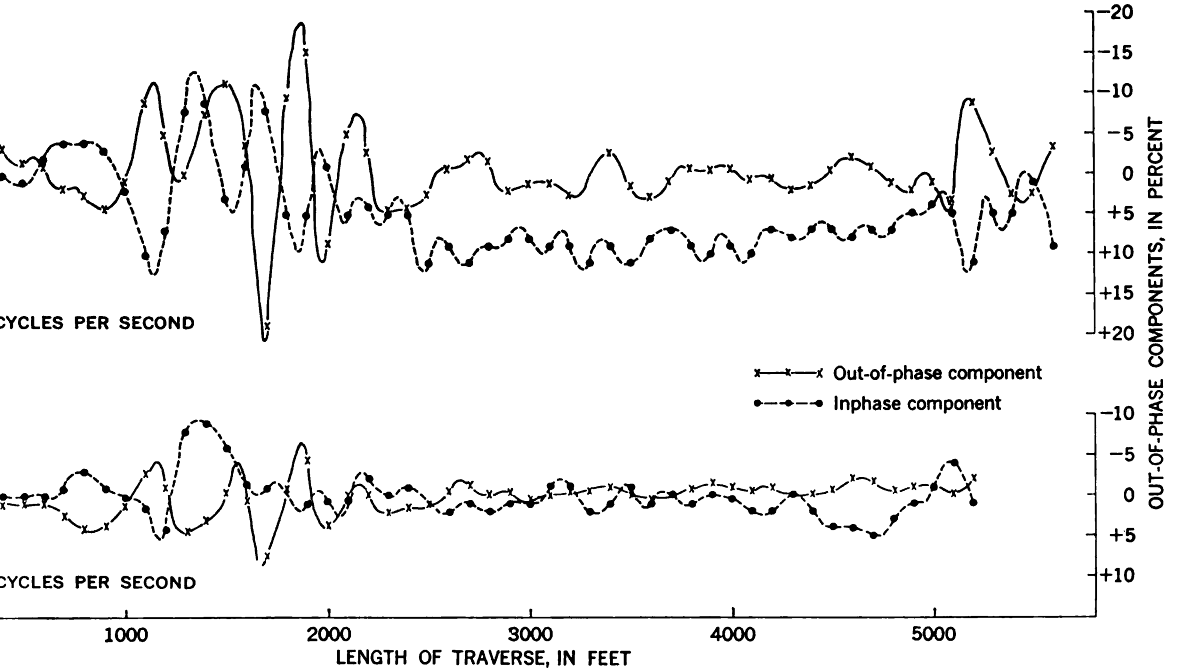


FIGURE 9.—Comparison of profiles at 2,000 and 8,000 cps for electromagnetic traverse T–59X.

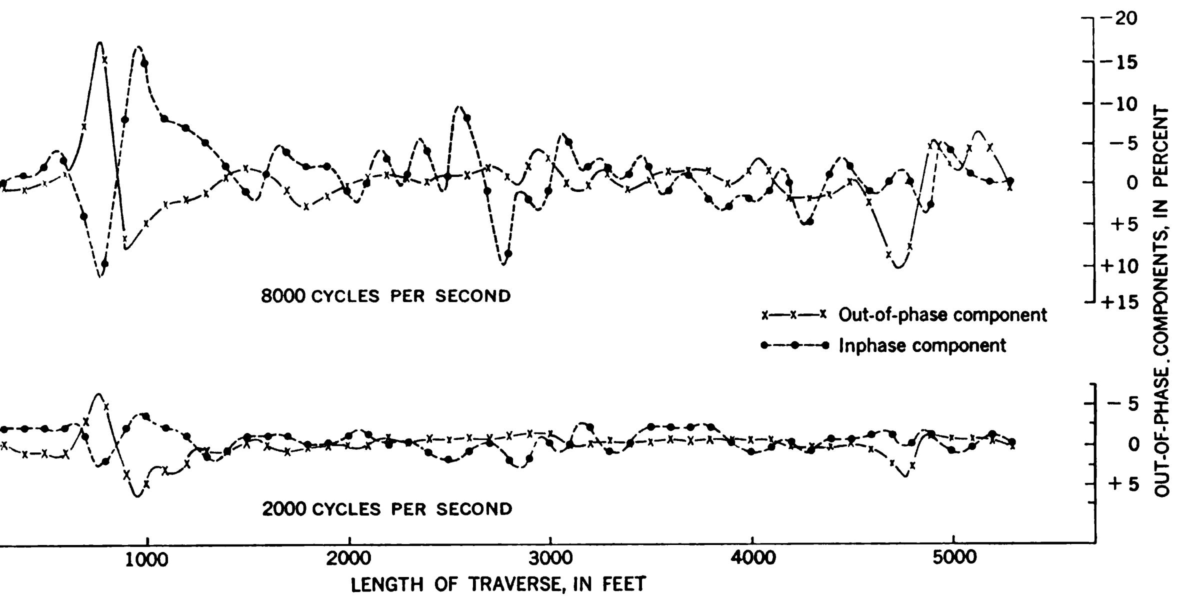


FIGURE 10.—Comparison of profiles at 2,000 and 8,000 cps for electromagnetic traverse T–73X.

have a lower conductivity than the cen- a vertical coplanar coil arrangement, er a thin vertical sheet striking 90° is a low, and a negative for the inphase e components, respectively. The oppo- a wide massive conductor. Therefore, zone on T–85X must represent a series ive beds sandwiched between insulating beds, rather than one massive conductor. This interpretation is substantiated by the presence of many minor features on the curves for the other coil arrangements.

For horizontal coils, at 2,000 cps the out-of-phase curve is somewhat smoother and more suggestive of a single massive conductor than the inphase curve, whereas at 8,000 cps the inphase curve is smoother. The out-of-phase curve is generally the smoothest and most nearly resembles model curves over conductors having a simple shape for relatively small values of the product of conductivity and frequency, whereas the inphase curve is the smoothest for relatively large values.

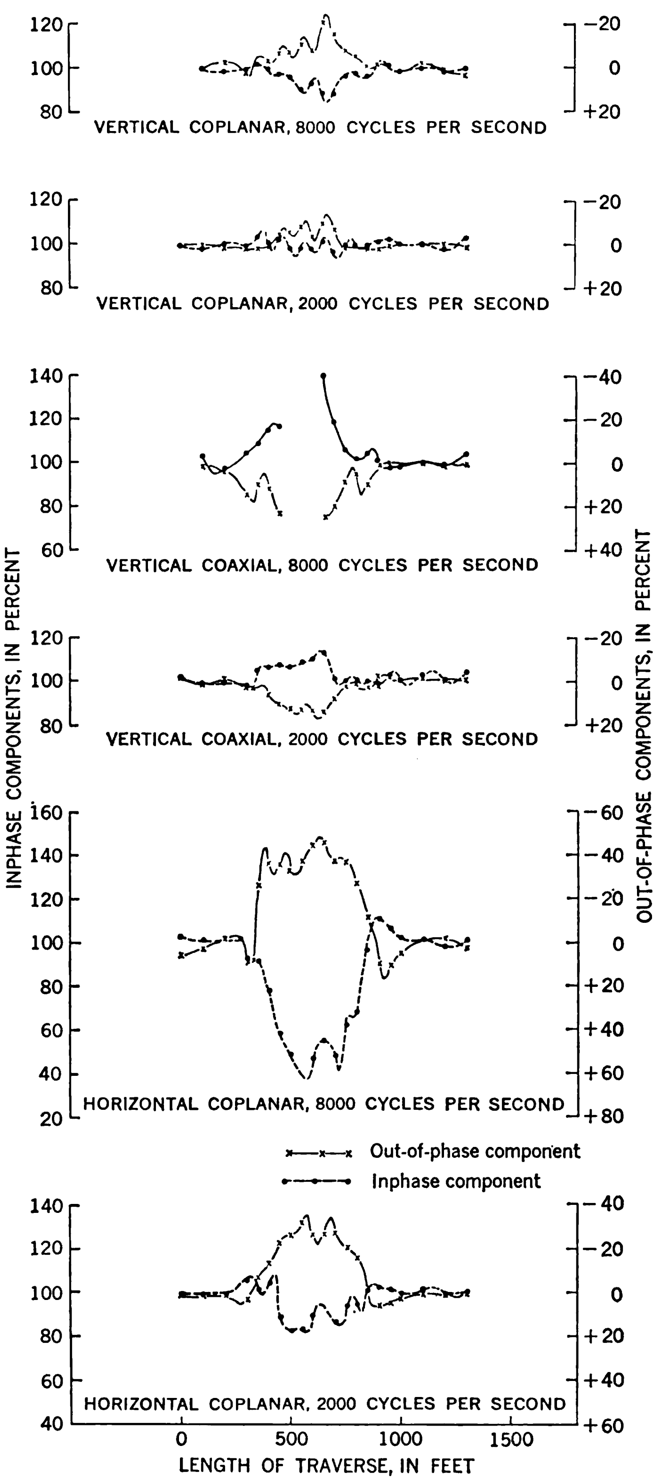


FIGURE 11.—Comparisons of profiles at 2,000 and 8,000 cps for horizontal coplanar, vertical coplanar, and vertical coaxial coil arrangements for electromagnetic traverse T–85X.

As usual, on T–85X the horizontal coplanar arrangement yielded the largest anomalies, and the vertical coplanar arrangement yielded the smallest.

Traverse T–94X (fig. 12) intersects three conductive zones at an angle of about 75° to the strike. The westernmost zone is centered at 620 feet east on T–94X and is 50–100 feet wide. The horizontal coplanar curves indicate a westward dip of this conductor, whereas the vertical coaxial curves indicate a slight eastward dip. This discrepancy may exist because the conductor is inhomogeneous, or because the vertical coaxial curve has not been drawn properly through the measured points.

A narrow conductor, probably no wider than 20 feet, occurs at 1,820 feet east, and a weak conductor occurs at about 2,020 feet east. Although the curves for horizontal coils suggest a westward dip, the anomalies from these two conductors overlap and the dip cannot be definitely determined. At first inspection the vertical coaxial curves suggest an eastward dip, because the low on the west side of the east conductor is superimposed on the low on the east side of the west conductor. For these conductors the vertical coplanar arrangement is almost as sensitive as the vertical coaxial arrangement, and the anomalies obtained using the former arrangement are simpler.

Traverse T–95X (fig. 13) was run at an angle of about 25° to the easternmost two of the conductive zones cut by T–94X, to provide a comparison of results obtained at an acute angle with results obtained at a high angle.

As expected, on T–95X the anomalies for horizontal coils are predominantly highs and positives for the inphase and out-of-phase components, respectively. The axis of the minor conductor is at about 1,100 feet north and the axis of the major conductor is at about 1,520 feet north. For vertical coaxial coils the anomalies are much larger on T–95X than on T–94X, whereas for vertical coplanar coils the anomalies are smaller and are reversed in sign. Lack of comparable model data prevents a detailed interpretation of these anomalies. Comparison of the amplitudes of the anomalies obtained on T–94X and T–95X demonstrates that, in general, horizontal coils are more sensitive than vertical coils.

SUMMARY OF ELECTROMAGNETIC RESULTS

Results from the Island Falls quadrangle show that individual conducting zones or belts of conductors can be mapped continuously for many miles. Strike trends can be delineated; in addition, deductions can be made as to the dip of the beds and simple structures can be traced. The geologic map of the Island Falls quadrangle is much more detailed than it would have been without electromagnetic data. Also, the interpretation of some of the major features such as the northwest extension of the Weeksboro–Lunksoos Lake anticline and folding in the Baston Brook salient southeast of Mattawamkeag Hill are based on the electromagnetic and other geophysical data.

The time and cost of electromagnetic surveying are much less than for drilling or trenching to obtain comparable information. A few reconnaissance traverses suffice to locate areas containing conductors, so that an entire quadrangle need not be surveyed in detail. In the Island Falls quadrangle, considerably less time and money were spent on the electromagnetic survey than on the regular geologic mapping.

This study demonstrates that if conductive strata are present in areas extensively covered with relatively thin overburden, electromagnetic surveys can be a valuable supplement to conventional geologic mapping on a quadrangle scale. Metamorphosed rocks which are highly conductive and can be detected easily by electromagnetic measurements include black carbona-

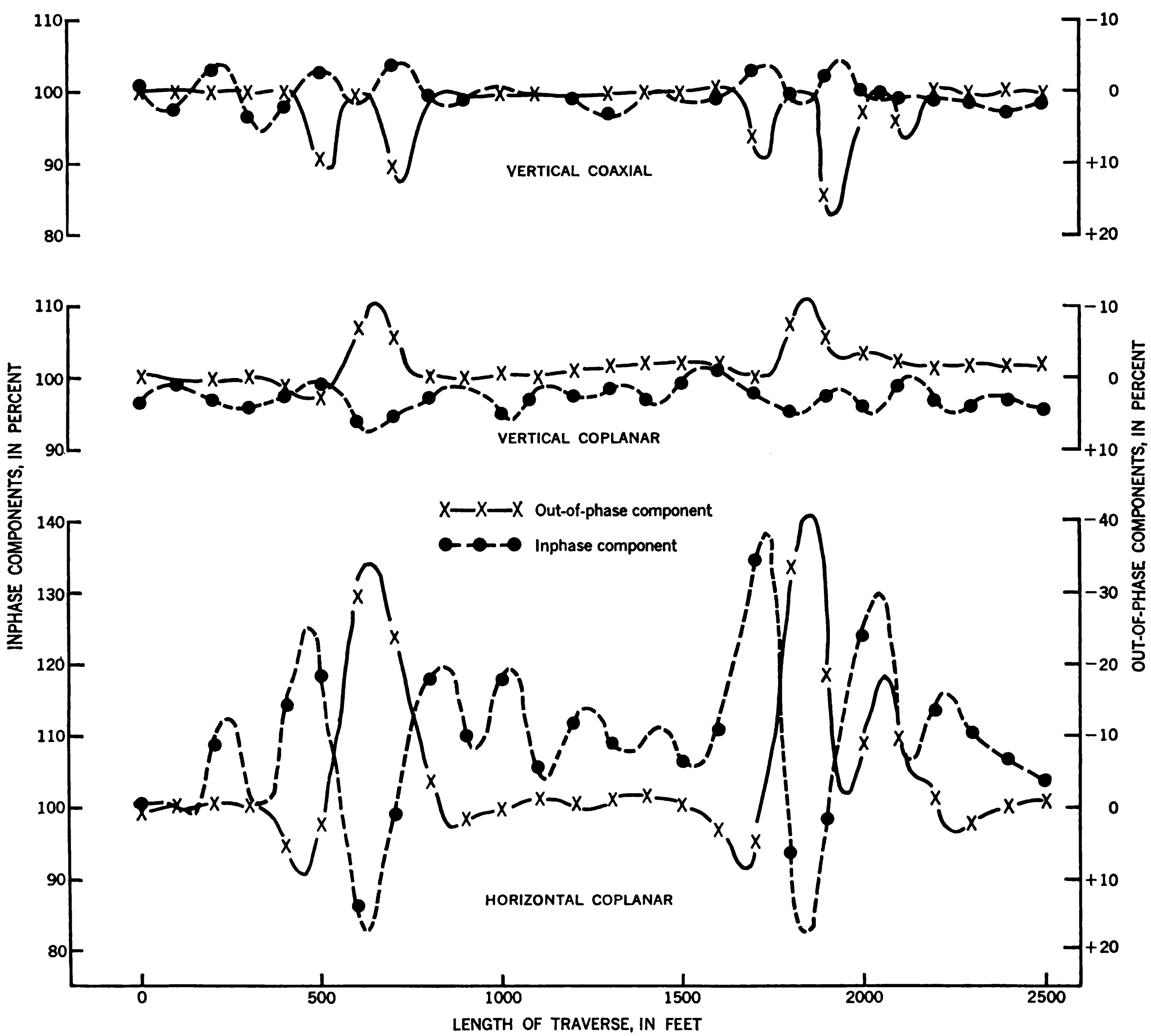


Figure 12.—Comparison of profiles for horizontal coplanar, vertical coplanar, and vertical coaxial coil arrangements for electromagnetic traverse T–94X.

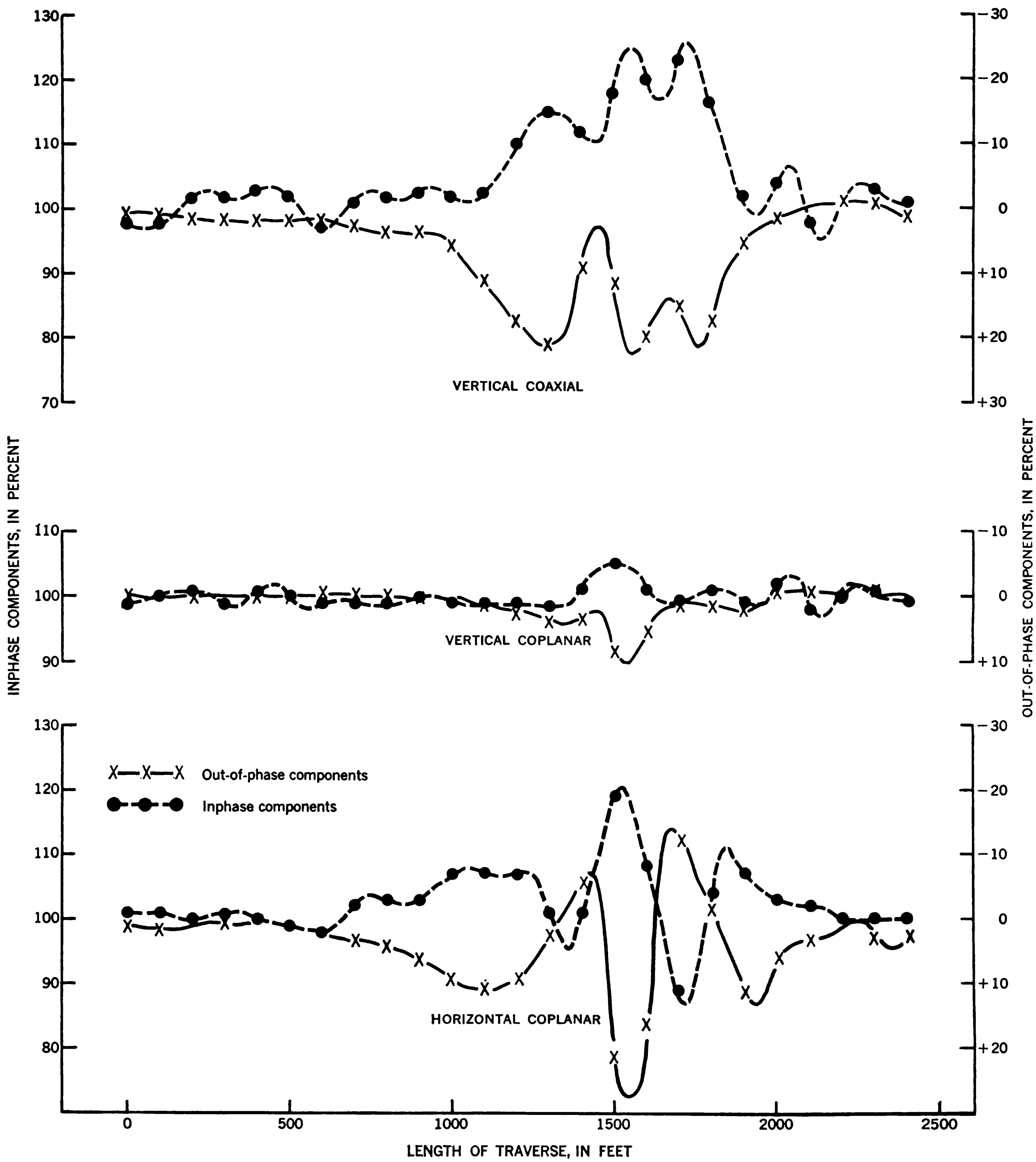


FIGURE 13.—Comparison of profiles for horizontal coplanar, vertical coplanar, and vertical coaxial coil arrangements for electromagnetic traverse T–95X.

ceous slate, such as is found in the Island Falls quadrangle and many other parts of northern Maine; graphitic schist; banded iron formations containing magnetite or specular hematite, such as those in the Lake Superior region; and rocks containing sulfides, such as pyrite and pyrrhotite. The grade of metamorphism and the resulting texture are as important as the percentage of conducting minerals in determining the conductivity of the rock. In the Island Falls quadrangle, chlorite-grade metamorphism was sufficient to render carbonaceous strata conductive; a much higher grade of metamorphism may be required to make rocks bearing syngenetic sulfides conductive. In order for a thin bed to be detected by 2,000-cps slingram measurements, the product of the conductivity and thickness should be about 1 mho or greater.

Improvements in electromagnetic equipment and techniques are being made, and there is increasing interest in the geology and economic resources of areas of extensive cover, which often have been ignored in the past owing to the difficulty of geologic mapping by conventional techniques. These changes should result in an increasing use of electromagnetic methods in geologic mapping.

MAGNETIC SURVEYS

An aeromagnetic map of the Island Falls quadrangle has been published without text by the U.S. Geological Survey (Dempsey, 1962).

The largest magnetic anomalies in the quadrangle occur over the mafic volcanic rocks of the Mount Chase area. Lesser anomalies are found over slate beds in the Allsbury Formation; with a few exceptions, as discussed in later pages, the other rocks exposed in the quadrangle are only slightly magnetic.

A pattern of discontinuous anomalies roughly outlines the volcanic belt along the ridges dominated by Mount Chase as far north as the West Branch Mattawamkeag River. Rocks along the southeast side of the ridge tend to be most magnetic; those on the northwest side are more silicic and less magnetic. Mapping of individual units within the volcanic rocks of the Mount Chase area is not sufficiently detailed to permit correlation of magnetic lows and highs with rock types, but in general the highs coincide with the thickest belts of spilite. Magnetic anomalies show little correlation with topographic features.

The contacts of the volcanic rocks of the Mount Chase area are not sharply defined by the aeromagnetic map; on the southeast side there are parallel anomalies in the Allsbury Formation, and on the northwest side some of the volcanic rocks are not very magnetic. Northwest of the ridge several sharp magnetic lows occur which are probably caused by induced rather than remanent magnetization. A broad gentle low extends northwest well over the Rockabema Quartz Diorite. This low is probably due partly to very low susceptibility in the quartz diorite and partly to the lows induced by the adjacent volcanic rocks. Comparison of some individual anomalies with calculated curves indicates that the volcanic rocks in the Mount Chase ridge dip steeply to the southeast (J. W. Allingham, oral commun., 1961).

Northeast of the West Branch Mattawamkeag River, the anomalies over the volcanic rocks of the Mount Chase area are relatively small. They serve to distinguish volcanic rocks from the quartz diorite on the north, but not from the Allsbury Formation on the south.

At Green Mountain and the Lane Brook Hills, the volcanic rocks are outlined by a magnetic trend which is more pronounced farther west in the Shin Pond quadrangle. Small anomalies indicate that a unit of these volcanic rocks strikes northeast through Lane Brook Pond.

Moderately large magnetic anomalies, particularly near the ridge extending from Mount Chase to Shoaler Mountain, distinguish the Allsbury Formation from other sedimentary units in the quadrangle. Individual magnetic units within the Allsbury Formation are not well defined by the aeromagnetic map. For the present study, therefore, a few ground magnetic traverses across the Allsbury Formation were run to aid in the interpretation of the aeromagnetic data. A Schmidt-type vertical balance was used. No corrections were made for diurnal variations, which appeared to be small relative to the magnitude of the anomalies; the same arbitrary datum was selected for all traverses.

The ground magnetic results correlated in part with electromagnetic results, so the two sets of data are plotted together on coincident profiles (fig. 14). The sharpness of the magnetic anomalies indicates that the magnetic rocks are near the surface.

Traverses T–29M and T–30M (fig. 14) show that the conductive black slate and chert at Kilgore Knoll are responsible for an 800-gamma anomaly. These rocks are much more magnetic than the adjacent volcanic rocks. In the middle of T–29 and T–29M there is good correlation between an electromagnetic low, caused by a conductive zone striking at an acute angle to the traverse, and a broad magnetic high. Also, on T–43M and T–29M magnetic anomalies correlate in part with very weak electromagnetic anomalies.

Traverse T–41M and the corresponding part of T–41 are both flat.

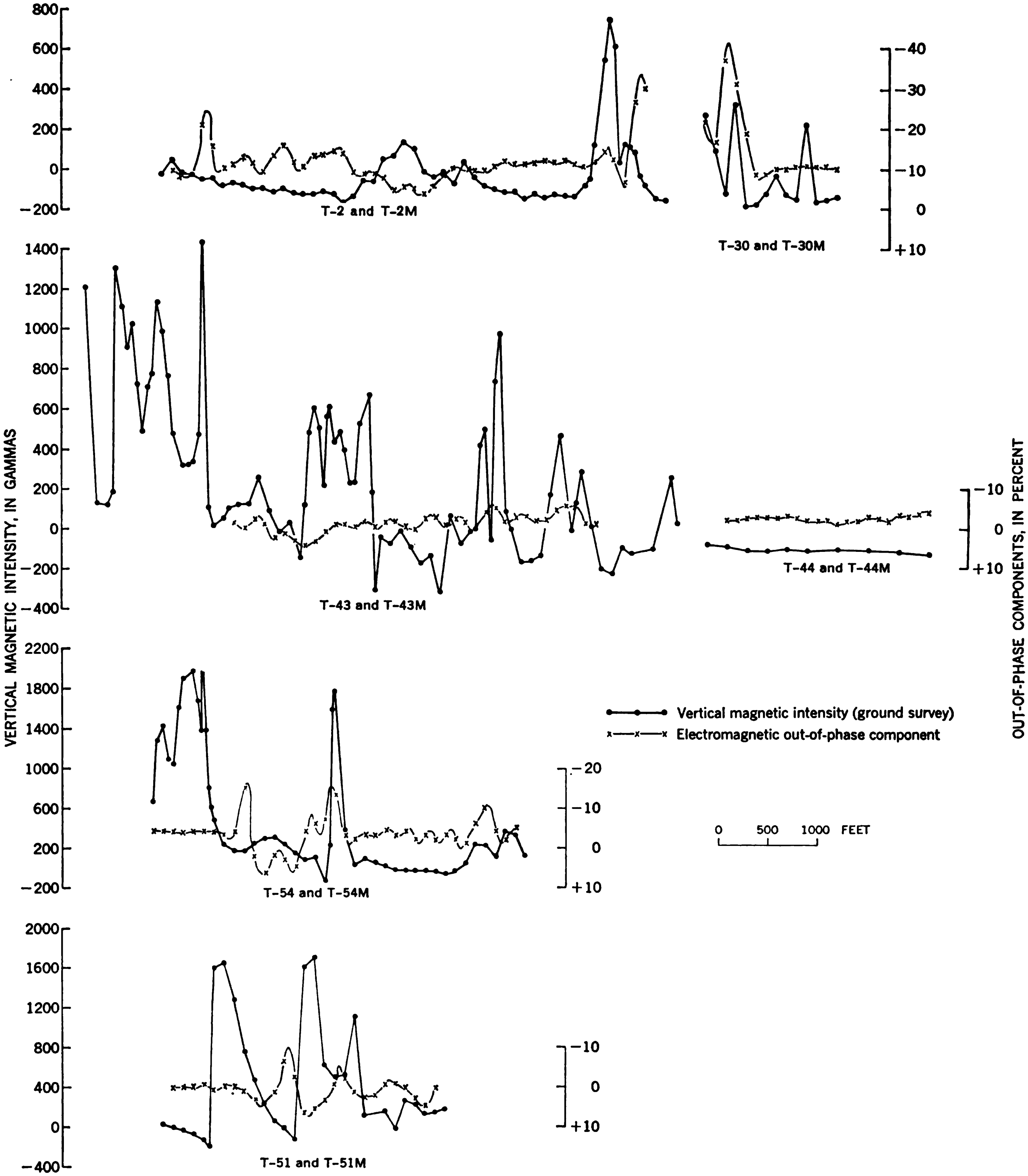


Figure 14.—Comparison of ground magnetic and electromagnetic profiles for selected traverses.

On T–54 and T–54M there is good correspondence between two electromagnetic and two magnetic anomalies. On this traverse the edge of the conductive zone either coincides with the contact between the volcanic rocks and sedimentary rocks or is very close to it.

The only ground magnetic anomaly that is sufficiently smooth to permit quantitative interpretation is at the west end of T–51M. Outcrops of volcanic rocks striking northeast were observed near the peak. The anomaly must be caused by a sill or other distinct unit dipping to the southwest. Such a dip is indicated also by the fact that the edge of the conductive zone overlaps the beginning of the magnetic anomaly; conductive rocks must therefore overlie the downdip part of the magnetic unit. Magnetic anomalies occur in the conductive belt, although individual peaks do not coincide with electromagnetic peaks.

As far as is known, most of the magnetic beds in the Allsbury Formation are dark slates containing magnetite as the primary magnetic constituent. The linear nature of the aeromagnetic anomalies and their coincidence with conductive zones indicate that the magnetic beds are probably continuous. It is very likely, that detailed ground magnetic surveys would have been a valuable supplement to the electromagnetic method, particularly in areas such as the vicinity of T–43, where the electromagnetic anomalies are very weak.

The elongated aeromagnetic anomalies which occur 2–4 miles south of Knowles Corner and immediately northeast of Baston Brook tend to confirm the presence of black slates as deduced from the electromagnetic results. All of the magnetic trends in the Allsbury Formation are interrupted by a low that follows the West Branch Mattawamkeag River. A small anomaly at De Lette Ridge is probably related to the presence of hornfels around the intrusive mass of granite, and the small, sharp anomalies east and northeast of the town of Island Falls may be caused by disseminated pyrrhotite in the contact-metamorphic zone surrounding the Pleasant Lake pluton.

The contours swinging in a gentle arc about Belvedere School at the south border of the quadrangle suggest a large magnetic body at depth in the Sherman quadrangle.

Small aeromagnetic anomalies of unknown origin occur over the Grand Pitch Formation northeast of Frost and Adams Ridge, southwest of Knowles Corner, and southwest of Green Mountain Pond. The anomaly southwest of Knowles Corner is near the contact of the Grand Pitch Formation with the Rockabema Quartz Diorite, and may be caused by magnetite associated with the intrusion. A small magnetic trend in the northwest corner of the quadrangle probably coincides with an outcrop of quartz porphyry in the belt of undifferentiated Silurian rocks near Lane Brook. The magnetic gradient in the extreme northwest corner of the quadrangle is related to a large volcanic mass that crops out to the west in the Shin Pond quadrangle; the gradient is probably also related to unknown magnetic bodies immediately north of the quadrangle boundary as inferred from the aeromagnetic map of the adjoining Oxbow quadrangle. Volcanic rocks may underlie the northwest limb of the Wadeligh Bog syncline at shallow depth.

The aeromagnetic map provided a valuable framework for the geologic studies of the quadrangle by outlining areas containing magnetic rocks at or near the surface. In a few localities, geologic contacts are inferred from the aeromagnetic map, although, in general, the resolution of the aeromagnetic data is not adequate for locating contacts. The ground magnetic traverses pinpointed the sources of the magnetic anomalies in the Allsbury Formation, and detailed ground magnetic surveys might have been a valuable supplement to the electromagnetic surveys in tracing marker beds within the Allsbury. Subunits could probably be delineated in the volcanic rocks of the Mount Chase area by ground magnetic surveys. Additional magnetic surveys would not have been helpful in mapping units within the Grand Pitch Formation. There are several very small anomalies in the Mattawamkeag Formation, and a few beds within this formation might have been traced by ground magnetic surveys.

REFERENCES CITED

Boucot, A. J., 1961, Stratigraphy of the Moose River synclinorium, Maine: U.S. Geol. Survey Bull. 1111–E, p. 153–188.

Daly, R. A., 1914, Igneous rocks and their origin: New York, McGraw-Hill Book Co., 563 p.

Dempsey, W. J., 1962, Aeromagnetic map of the Island Falls quadrangle, Aroostook and Penobscot Counties, Maine: U.S. Geol. Survey Geophys. Inv. Map GP–293.

Dickinson, W. R., 1962, Metasomatic quartz keratophyre in central Oregon: Am. Jour. Sci., v. 260, p. 249–266.

Ekren, E. B., 1961, Volcanic rocks of Ordovician age in the Mount Chase ridge, Island Falls quadrangle, Maine, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D43–D46.

Faul, Henry, Stern, T. W., Thomas, H. H., and Elmore, P. L. D., 1963, Ages of intrusion and metamorphism in the northern Appalachians: Am. Jour. Sci., v. 261, p. 1–19.

Frischknecht, F. C., 1959, Scandinavian electromagnetic prospecting: Am. Inst. Mining Metall. Engineers Trans., v. 214, p. 932–937.

Frischknecht, F. C., and Ekren, E. B., 1960, Mapping conductive strata by electromagnetic methods, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400–B, p. B121–B125.

Frischknecht, F. C., and Mangan, G. B., 1960, Preliminary report on electromagnetic model studies: U.S. Geol. Survey open-file report, 12 p.

Gilluly, James, 1935, Keratophyres of eastern Oregon and the spilite problem: Am. Jour. Sci., ser. 5, v. 29, p. 225–252, 336–352.

Harker, Alfred, 1956, Metamorphism: 3d ed. New York, E. P. Dutton & Co., 362 p.

Neuerburg, G. J., 1961, A method of mineral separation using hydrofluoric acid: Am. Mineralogist, v. 46, p. 1498–1501.

Neuman, R. B., 1960, Pre-Silurian stratigraphy in the Shin Pond and Stacyville quadrangles, Maine, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400–B, p. B166–B168.

———1962, The Grand Pitch Formation—new name for the Grand Falls Formation (Cambrian?) in northeastern Maine: Am. Jour. Sci., v. 260, p. 794–797.

———1964, Fossils in Ordovician tuff, northeastern Maine: U.S. Geol. Survey Bull. 1181–E, 38 p.

———1967, Bedrock geology of the Shin Pond and Stacyville quadrangles, Maine: U.S. Geol. Survey Prof. Paper 524–I (in press).

Orville, P. M., 1963, Alkali ion exchange between vapor feldspar phases: Am. Jour. Sci., v. 261, p. 201–237.

Pavlides, Louis, 1962, Geology and manganese deposits of the Maple and Hovey Mountains area, Aroostook County, Maine: U.S. Geol. Survey Prof. Paper 362, 116 p. [1963].

Pavlides, Louis, and Berry, W. B. N., 1966, Graptolite-bearing Silurian rocks of the Houlton-Smyrna Mills area, Aroostook County, Maine, *in* Geological Survey research 1966: U.S. Geol. Survey Prof. Paper 550–B, p. B51–B61.

Pavlides, Louis, and Canney, F. C., 1964, Geological and geochemical reconnaissance, southern part of the Smyrna Mills quadrangle, Aroostook County, Maine, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–D, p. D96–D99.

Pavlides, Louis, Mencher, Ely, Naylor, R. S., and Boucot, A. J., 1964, Outline of the stratigraphic and tectonic features of northeastern Maine, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 501–C, p. C28–C38.

Pavlides, Louis, Neuman, R. B., and Berry, W. B. N., 1961, Age of the "ribbon rock" of Aroostook County, Maine, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–B, p. B65–B67.

Ruedemann, Rudolf, 1942, *Oldhamia* and the Rensselaer grit problem: New York State Mus. Bull. 327, p. 5–18.

Ruedemann, Rudolf, and Smith, E. S. C., 1935, The Ordovician in Maine: Am. Jour. Sci., ser. 5, v. 30, p. 353–355.

Smith, E. S. C., 1928, The Cambrian in northern Maine: Am. Jour. Sci., ser. 5, v. 15, p. 484–486.

Swanson, H. E., 1960, Model studies of an apparatus for electromagnetic prospecting: Am. Inst. Mining Metall. Engineers preprint 60L83.

Ward, S. H., 1959, Unique determination of conductivity, susceptibility, size and depth in multifrequency electromagnetic exploration: Geophysics, v. 24, p. 531–546.

...rt Union Formation
...e, sandstone and siltstone; conglomerates
...in pre-Cretaceous rocks; contains fossil spores,
plants, wood, fresh-water mollusks, and vertebrates

UNCONFORMITY