Geology of the Area East and Southeast of Livingston, Park County Montana

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A CONTRIBUTION TO GENERAL GEOLOGY

GEOLOGY OF THE AREA EAST AND SOUTHEAST OF LIVINGSTON, PARK COUNTY, MONTANA

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ABSTRACT

The area lies generally east and southeast of Livingston, Park County, Mont. It is bordered on the east by the 110° 15′ meridian of longitude, on the west by the Yellowstone River and the 110° 30′ meridian, and on the north and south by the 45° 45′ and 45° 30′ parallels of latitude. The area lies across the boundary of the Great Plains and Rocky Mountains physiographic provinces where the Crazy Mountains syncline adjoins the Beartooth Mountains and the Absaroka Range southeast of Livingston. Altitudes range from 4,200 feet to about 10,000 feet. The Yellowstone River drains the area, and the smaller Shields River, which drains the land north of the mapped area, joins it near Livingston. The average annual rainfall of the area is about 15 inches. Livingston, which had a population of 7,683 in 1950, is the only town within the area.

Pre-Cambrian metamorphic and igneous rocks, which include a part of the Stillwater complex, are exposed in the Beartooth Mountains. The sedimentary rocks range in age from Middle Cambrian to Upper Cretaceous and possibly Tertiary. They are at least 15,000 feet thick and crop out along the mountain flanks and in the plains.

The Paleozoic strata consist mainly of Cambrian shale and limestone, dolomite of Ordovician age, Devonian and Mississippian limestone and shale, and quartzite of Pennsylvanian age. The Silurian, Permian, and Triassic systems are not represented. Mesozoic strata include Jurassic shale and sandstone and a thick section of Cretaceous shale and sandstone. A thick sequence of tuffaceous beds, the Livingston formation, forms the upper part of the Upper Cretaceous series. With the possible exception of the uppermost part of the Livingston formation, there are no Tertiary deposits within the mapped area. Quaternary deposits include small moraines and terrace and pediment gravels, as well as a few landslides and alluvial fans.

The rocks are complexly folded and faulted in much of the area. Southeast of Livingston the west and north flanks of the Beartooth Mountains are bordered by high-angle faults. A near-vertical fault that has as much as 1,800 feet displacement within the mapped area marks the west edge of the Beartooth Mountains. High-angle reverse faults that dip northeastward along the north side of the mountains have displacements of as much as 3,000 feet.

The area north of the Beartooth Mountains is the southwest edge of the Crazy Mountains syncline, which is a 100-mile-long structural downwarp that is nearly

alined with the Bighorn Basin of Wyoming and Montana to the southeast. With the exception of the Mission Creek and Livingston anticlines, which are close to the mountain front, folds and faults within the Crazy Mountains syncline trend at right angles to the mountain front. Some of these folds are nearly isoclinal; all are faulted along one flank, and all but Hunters anticline plunge moderately to steeply away from the mountains.

During the early part of this century coal was mined and coked along Coke Creek west of Livingston, but coal has not been mined for other than domestic use within the mapped area. Thin coal beds that occur in the Cretaceous strata above the Virgelle sandstone west of Mission Creek are in about the same stratigraphic position as those mined along Coke Creek.

Neither oil nor gas has been produced, and only four exploratory wells have been drilled deeper than 1,500 feet. Only one of these, the Richfield 1 Weiss, was located on a structure with possible surface closure. It is on the axis of Mission Creek anticline west of a fault that crosses the axis. The test was abandoned in Jurassic strata without known shows of oil or gas. The only other anticline with mapped surface closure is Hunters anticline.

The exposed bentonite beds are thin and lie beneath thick overburden. Limestone had been quarried and kilned in the Yellowstone River canyon south of Livingston in the first decade of the century, but has not been utilized since. Calcite occurs in veins in much of the area of outcrop of the Livingston formation; during World War II it was mined in adjacent areas, reportedly for its optical properties.

Metallic mineral deposits have not been discovered. The Stillwater complex contains chromite near Boulder River a few miles southeast of Mount Rae, but no chromite has been discovered in the Stillwater complex within the mapped area.

INTRODUCTION

LOCATION AND EXTENT OF THE AREA

This report and the accompanying maps describe the geology of about 250 square miles in Park County, Mont. The area lies south and east of the Yellowstone River and includes the Mount Rae, Elton, Mission, and Livingston Peak 7½-minute quadrangles and the area east of the Yellowstone River in the Brisbin and Livingston 7½-minute quadrangles. The area is thus bounded on the east by the 110° 15′ meridian of longitude, on the west by the Yellowstone River and the 110° 30′ meridian, and on the north and south by the 45° 45′ and 45° 30′ parallels of latitude as shown in figure 58.

PURPOSE OF REPORT

This report was prepared as part of the Interior Department program for the development of the Missouri River basin. Sedimentary rocks and their structures were studied to evaluate the oil and gas possibilities of the area, and the surficial deposits were examined to indicate their value as aggregate.

FIELD WORK AND ACKNOWLEDGMENTS

The area was mapped during the summers of 1949 and 1950; the writer was assisted by G. E. Prichard in 1949 and by A. A. Meyerhoff

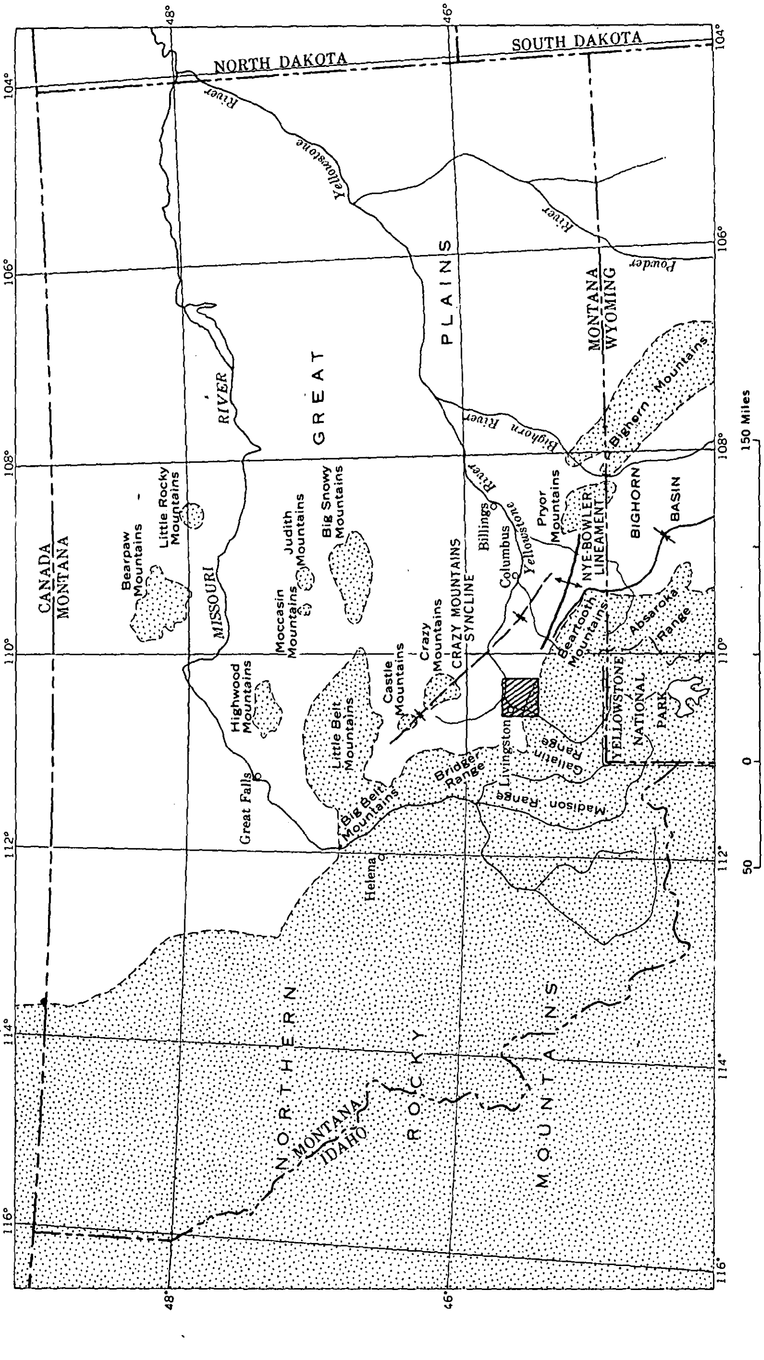

FIGURE 58.—Index sketch map showing relation of mapped area to Crazy Mountains syncline, Bighorn Basin, and mountainous areas of Montana and northern Wyoming.

in 1950. All geologic data were drawn on aerial photos of 1:24,000 scale and later transferred to topographic base maps. Altitudes for the control of structure contours were taken from points of intersection of formation contacts and topographic contours (pl. 34).

PREVIOUS WORK AND PUBLICATIONS

The geology of the area was discussed briefly by Hayden (1872, 1873) in the 5th and 6th Annual Reports of the U. S. Geological Survey of the Territories. A geologic map of the Livingston one-degree quadrangle appeared in Folio 1 of the U. S. Geological Survey geologic atlas series (Iddings and Weed, 1894). Parts of the area covered by this report were mapped by Weed (1893), Stone and Calvert (1910), and Lammers (1937). Geomorphic problems have been discussed by Alden (1932) and Horberg (1940).

A report by the writer on the geology of this area was placed on open file in Geological Survey offices on July 9, 1952.[1]

GEOGRAPHY

SURFACE FEATURES AND RELIEF

The area covered by this report includes the northwest corner of the Beartooth Mountains and adjacent parts of the Yellowstone River valley. The Beartooth Mountains are part of the Middle Rocky Mountains physiographic province, and most of the mountainous part of the area lies within the Gallatin National Forest. The Yellowstone River flows northward from Yellowstone National Park between the Beartooth Mountains and the Gallatin Range to Livingston where it turns eastward and crosses the south edge of the Crazy Mountains syncline. The Crazy Mountains syncline, named from the mountains located about in the center of the 100-mile-long synclinal area, is part of the Great Plains.

Altitudes within the area range from 4,200 feet on the Yellowstone River to more than 10,000 feet in the mountains in the southern part of the area. A large part of the valley is below an altitude of 5,000 feet, whereas, many of the ridges and peaks of the mountains are 8,000 feet or more in altitude.

CLIMATE AND WATER SUPPLY

The average annual rainfall at Livingston is about 15 inches. Other climatic data are summarized in the table below. The Yellowstone River is the main stream of the area; it is joined from the north by the Shields River which drains much of the area west of the Crazy Mountains and east of the Bridger Range. Several perennial streams

[1] Richards, P. W., 1952, Structural geology of the Crazy Mountains syncline-Beartooth Mountains border east of Livingston, Mont.: U. S. Geol. Survey open-file report.

Climatological Data for Livingston, Park County, Mont.

[Average date through 1930 of last killing frost in spring, May 16; first killing frost in autumn, September 20; length of growing season, 127 days. Data from several climatological summaries of the United States, U. S. Weather Bureau]

	Length of record, in years	Through 1930													1931–40	1941–50
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Annual	Annual
Average precipitation, in inches	39	0.63	0.58	0.88	1.39	3.08	1.98	1.47	1.13	1.57	1.19	0.93	0.60	15.40	11.37	14.93
Temperature, in degrees Fahrenheit:																
Average	28	25.4	28.3	34.6	44.0	52.1	60.4	68.2	67.0	57.1	48.0	36.5	29.0	45.9	46.3	45.0
Maximum	28	34.6	38.1	45.4	56.3	65.4	74.7	84.0	83.0	71.3	60.0	45.7	37.1	58.0		
Minimum	28	16.2	18.5	23.9	31.6	38.8	46.1	52.4	50.9	42.9	36.1	27.3	20.8	33.8		
Highest	28	60	64	75	89	92	99	106	103	96	89	70	69		104	99
Lowest	28	−39	−34	−26	2	10	29	35	32	12	−3	−20	−40		−45	−34

that rise in the Beartooth Mountains enter the Yellowstone River within the area. The discharge of the Yellowstone River near Livingston was an average of about 3,600 second-feet for 23 years during times that records were kept between 1897 and 1949. During the same period the maximum discharge of the Yellowstone River was 30,600 second-feet on June 20, 1943, and the minimum daily discharge was 590 cfs on January 22, 1940. The average discharge of the Shields River a few miles above its mouth for the 18 years during which records were kept between 1921 and 1949 was 146 cfs.

SETTLEMENT AND POPULATION

Livingston, the county seat of Park County, is the only town within the area. It had a population of 7,683 in 1950. The main line of the Northern Pacific Railway goes through Livingston; a branch extends southward from Livingston to Gardiner, Mont., at the north entrance to Yellowstone National Park, and a branch runs northward from Livingston into the Shields River valley. Highways U. S. 10 and U. S. 89 pass through Livingston.

METAMORPHIC AND IGNEOUS ROCKS

METAMORPHIC ROCKS

The metamorphic rocks are a series of interbedded steeply dipping gneiss, schist, quartzite, and some marble. They are of pre-Cambrian age and are older than the unmetamorphosed Belt series, which is not found within the area.

STILLWATER COMPLEX

The Stillwater complex occurs only in the southeast corner of the Mount Rae quadrangle. It is an ultrabasic intrusive mass which, because of its chromite content, has been studied carefully at the type locality near Stillwater River canyon about 25 miles to the southeast of Mount Rae. In the Stillwater area the complex is divided into four zones: (1) the basal zone which is comprised of norite; (2) an ultramafic zone, consisting of bronzitite, harzburgite, which is associated with chromite near the middle of the zone, and dunite; (3) the banded zone, which is made up of norite, gabbro, and anorthosite; and (4) the upper zone, composed of anorthosite, norite, and gabbro (Peoples and Howland, 1940, p. 378).

The westernmost exposure of the Stillwater complex is in the Mount Rae quadrangle and it includes norite and anorthosite, which are probably part of the banded and upper zones (Howland and others, 1949, pl. 34). It is separated from the gneiss to the south and from Paleozoic strata on the west by faults. Shale of Cambrian age overlies the Stillwater complex along the north side of the outcrop. The Stillwater complex is younger than the metamorphic rocks but older than the granite in the Beartooth Mountains (Peoples and Howland, 1940, p. 376, 382). No deposits of chromite have been reported in the mapped area. Considerable prospecting for chromite has been carried on in the area east of West Boulder River a few miles southeast of the Mount Rae quadrangle (Howland and others, 1949).

GRANITE

Pink coarse-grained granite of pre-Cambrian age occurs in a small area south of the west end of the Stillwater complex. It is in fault contact with the Stillwater complex and possibly in fault contact with older metamorphic rocks to the east and west. The contact of the granite and the gneiss is concealed by talus and morainal debris. Granite is not distinguished from the metamorphic rocks on the geologic map.

DIABASE AND GABBRO

Diabase dikes were mapped along the north fork of Deep Creek and near Blacktail Lake. In the latter area a dike that strikes eastward through Blacktail Lake is nearly vertical and ranges from 20 to 40 feet in width. It extends a distance of at least 1 mile west of the lake and a few hundred feet east of the lake to a moraine. A similar dike, perhaps the same one but offset by a fault and concealed by the moraine, starts 1,200 feet to the south and continues eastward for a distance of at least 2,000 feet.

An irregular mass of gabbro is associated with the diabase in the north fork of Deep Creek. The rocks were determined by A. H. Makela of the Geological Survey. No dikes were observed in Paleozoic or younger rocks within the mapped area. Thick dikes and sills do occur, however, in the valleys of the Yellowstone River and Shields River north of the area.

SEDIMENTARY ROCKS

The sedimentary rocks, ranging in age from Middle Cambrian into Late Cretaceous and perhaps Tertiary, are about 15,000 feet thick. These strata, which are described briefly in plates 35 and 36, are seemingly concordant although the Silurian, Permian, and Triassic systems are missing. Paleozoic formations dip steeply northward along the Beartooth Mountains' front and are exposed in southward-facing cliffs. The overlying Jurassic strata likewise dip steeply and crop out in a narrow belt close to the base of the mountains, and the Cretaceous rocks dip northward from the edge of the mountains into the Crazy Mountains syncline.

Paleozoic formations (fig. 59) are mostly marine; the Jurassic system is continental and marine; and the lower one-third of the Cretaceous strata is mostly marine, while the upper two-thirds is continental. Two unconformities within the sequence represent at least one geologic period each. These occur between the Upper Ordovician Bighorn dolomite and the Devonian Jefferson limestone, and between the Pennsylvanian Quadrant quartzite and the Middle Jurassic Piper formation. In addition, an unconformity below the Bighorn dolomite represents Early and Middle Ordovician, and an erosional unconformity below the Amsden formation represents part of the Mississippian and perhaps part of the Pennsylvanian periods. Little is known of the unconformities that are within formations and represent considerably less than a period.

CAMBRIAN SYSTEM

The Cambrian system, which is about 1,000 feet thick near Shell Mountain, consists of a conformable sequence of shale and limestone

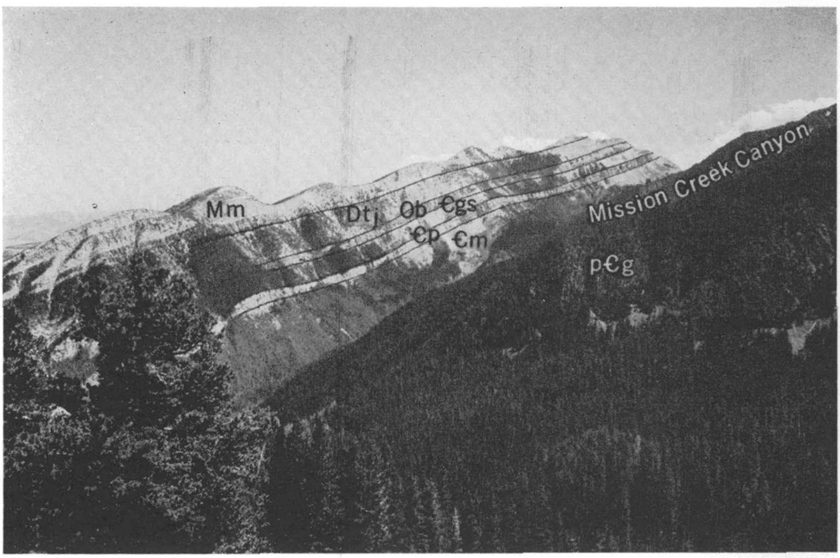

FIGURE 59.—Paleozoic strata along north flank of the Beartooth Mountains. View southeastward to Rough Draw. In descending order: Mm, Madison limestone; Dtj, Three Forks shale and Jefferson limestone; Ob, Bighorn dolomite; €gs, Grove Creek and Snowy Range formations; €p, Pilgrim limestone; €m, Middle Cambrian Park shale, Meagher limestone, Wolsey shale, and Flathead quartzite; p€g, pre-Cambrian gneiss.

above a lenticular basal sandstone. No Lower Cambrian rocks are known to occur in the area. Middle Cambrian strata are mostly shale, whereas Upper Cambrian strata are largely limestone. These strata have been divided into 4 Middle Cambrian and 3 Upper Cambrian formations. Narrow outcrops of the formations, caused by the very steep slopes on which the rocks are exposed, led the author to combine the 7 formations into 3 cartographic units. The 4 Middle Cambrian formations were mapped together, and the 3 Upper Cambrian formations were mapped as 2 units. The system lies upon upturned pre-Cambrian rocks that include granite, the ultrabasic Stillwater complex, and metamorphosed sedimentary rocks.

MIDDLE CAMBRIAN SERIES

The Middle Cambrian series is 625 feet thick and includes the basal Flathead quartzite, Wolsey shale, Meagher limestone, and Park shale which were accorded formational rank by Weed (1900) and redescribed by Deiss (1936). These formations are well exposed in saddles at the heads of East Baldy Basin and Rough Draw. The following stratigraphic section was measured at the head of Rough Draw, and the photograph (fig. 60) was taken at the head of East Baldy Basin.

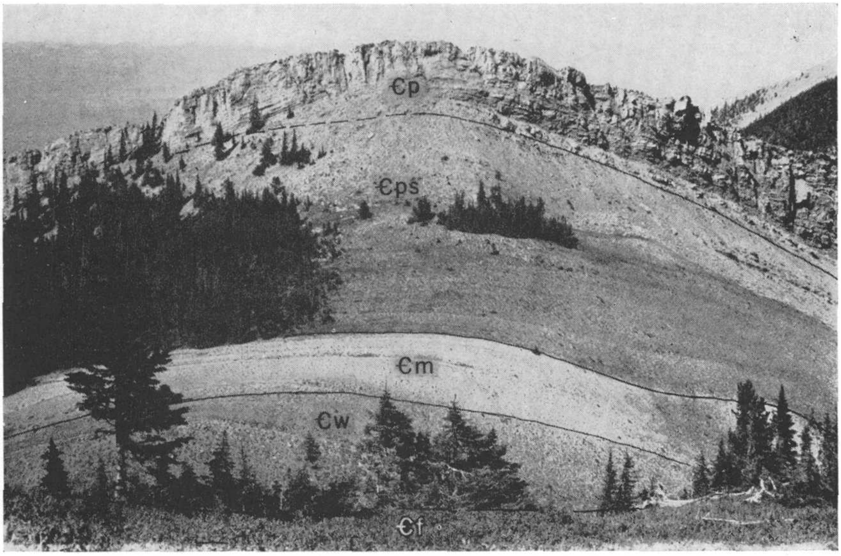

FIGURE 60.—Cambrian strata north of Livingston Peak. View northward across saddle at head of East Baldy Basin showing Upper Cambrian Pilgrim limestone (Єp) in cliff and Middle Cambrian formations (Єps, Park shale; Єm, Meagher limestone; Єw, Wolsey shale; Єf, Flathead quartzite).

Section of Middle Cambrian strata between head of Rough Draw and crest of Shell Mountain, all in or near SW¼ sec. 21, T. 3 S., R. 11 E. (unsurveyed), Park County, Mont.

	Feet
Pilgrim limestone: Basal part is a gray dense to finely crystalline limestone, much of which occurs as edgewise conglomerate; unit weathers to light blue or light green but is exposed only in a few places.	
Park shale:	
Shale and limestone; gray mostly finely crystalline glauconitic limestone and greenish-gray shale. Limestone in beds as much as 3 feet thick; the thicker beds are crystalline, probably fragmental; many limestones are ripple marked and many occur as flat-pebble conglomerate	92
Shale, greenish-gray; mostly concealed	119
Shale and limestone; interbedded greenish-gray shale and gray micaceous, probably silty, limestones, many marked by raindrop impressions	19
Shale, brownish-gray, weathers somewhat greenish-gray, notably fissile; may include thin beds of limestone	56
Shale and limestone; greenish-gray shale and gray crystalline (fragmental?) platy limestone; some limestone beds have abundant "bottom markings" on bedding planes, other limestones occur as flat-pebble conglomerate	94
Total Park shale	380
Meagher limestone:	
Limestone and shale; 1-inch beds of light-gray dense limestone in soft green shale. Unit weathers light yellowish gray and is conspicuous largely because of its color; it forms small ledges locally. Upper and, particularly, lower contacts gradational	65
Total Meagher limestone	65
Wolsey shale:	
Shale, greenish-gray, flaky, and few thin beds of gray silty brown-weathering limestone	29
Limestone, dense and finely crystalline, brown-weathering; some occurs as flat-pebble conglomerate. A little shale interbedded with limestone	11
Shale, greenish- and reddish- to brownish-gray; some of color probably result of weathering. Includes few thin beds of crystalline, in part, glauconitic limestone. Contact with Flathead quartzite concealed	65
Total Wolsey shale	105
Flathead quartzite:	
Quartzite and sandstone; gray to reddish-gray thick-bedded to massive sandstone that is mostly quartzite in upper 50 feet. Lower 25 feet contains hematite nodules. Layers of quartz granules, up to a few millimeters in diameter, occur in basal few feet. Lower part of formation in part crossbedded	75
Total Flathead quartzite	75
Total Middle Cambrian series	625
Pre-Cambrian metamorphic rocks.	

FLATHEAD QUARTZITE

The Flathead quartzite is gray to reddish-gray sandstone and quartzite. Gray quartz granules a few millimeters in diameter are common in the basal few inches. The topmost few feet of the Flathead in the outcrop at the head of Rough Draw is quartzite, whereas the underlying rock is interbedded sandstone and quartzite. Limonite and hematite nodules are common in the lower 25 feet.

The Flathead is not more than 75 feet thick in most outcrops, and it is absent in a number of localities, notably above the Stillwater complex and along much of the ridge north of the north fork of Deep Creek. Its absence is seemingly due to nondeposition over low hills of pre-Cambrian rock that remained above the sea bottom during transgression of Middle Cambrian seas.

WOLSEY SHALE

The Wolsey shale is about 100 feet thick and consists mostly of grayish-purple, brownish-gray, and greenish-gray shale. Limestone occurs in thin layers in most localities. Wherever the Flathead is missing the Wolsey lies upon the pre-Cambrian rocks. The basal part of the Wolsey shale is commonly covered. Although the formation was not measured in more than one locality, it is not noticeably thinner where it lies directly on the pre-Cambrian than where it is underlain by the Flathead quartzite.

MEAGHER LIMESTONE

The Meagher limestone consists of 65 feet of thin-bedded gray limestone and greenish-gray shale. The unit is distinct in appearance from the overlying and underlying beds (fig. 60) because the limestone makes small ledges and the weathered limestone and shale are light yellowish-gray. The Meagher is exposed in only a few places in the mapped area and is but a thin representative of the formation in adjacent areas to the north and west. According to Deiss (1936, p. 1331), the Meagher ranges more in thickness than any other Cambrian formation and is more than 400 feet thick along Beaver Creek in the Big Belt Mountains.

PARK SHALE

The Park shale is 380 feet thick and consists of interbedded greenish-gray and brownish-gray shale and gray crystalline glauconitic limestone. Much of the limestone occurs as flat-pebble conglomerate. The lower 300 feet is shale, but limestone becomes abundant and is dominant in the upper 80 feet. As the upper part is commonly concealed by talus from the overlying Pilgrim limestone, the top of the Park shale is difficult to determine. Hanson (1952, p. 15) notes that the contact is a "gradual passage" from shale to limestone in the Cooke City area, which is in the Beartooth Mountains about 50 miles southeast of Livingston.

Although the Park shale is the uppermost Middle Cambrian formation in south-central Montana, the contact between the Park shale and Pilgrim limestone does not everywhere coincide with the contact of Middle and Upper Cambrian strata. Denson noted that a Middle Cambrian fauna occurs in the basal part of the Pilgrim limestone at Nixon Gulch in the Three Forks quadrangle west of Livingston (Lochman and Duncan, 1944, p. 5).

UPPER CAMBRIAN SERIES

The Upper Cambrian series is 400 feet thick, which is in agreement with the reported average thickness for the series in the Livingston one-degree quadrangle (Iddings and Weed, 1894). Terminology of the Upper Cambrian formations is more complex than that of the Middle Cambrian formations, and detailed reviews of the nomenclature have been discussed by Deiss (1936), Sloss and Laird (1947), Lochman (1950), and Hanson (1952).

Peale (1893) divided the Upper Cambrian strata in the area of Three Forks, Mont. into the Mottled limestone, Dry Creek shale, and Pebbly limestone beds. These and the underlying *Obolella* shale (Park shale) were, according to Peale, the members of the Gallatin formation. Iddings and Weed (1894) referred to all of the Upper Cambrian strata in the Livingston quadrangle as the Gallatin limestone.

Weed (1900) established in central Montana, a standard section for Cambrian strata and described type localities in the Little Belt Mountains. His Upper Cambrian series consisted of the Pilgrim limestone, Dry Creek shale, and Yogo limestone. Dorf and Lochman (1940) proposed for the Upper Cambrain of south-central Montana the Maurice, Snowy Range, and Grove Creek formations. These would apply to the Upper Cambrian starta of the Beartooth Mountains.

There is apparent agreement by those who have written on Upper Cambrian stratigraphy of Montana that Weed must have considered the Dry Creek shale and Yogo limestone in the Little Belt Mountains to be stratigraphic equivalents of the Dry Creek shale and Pebbly limestone described by Peale in the Three Forks area. Deiss (1936, p. 1337), Sloss and Laird (1947, p. 1413–1415), and Lochman (1950, p. 2205–2206) have shown the fallacy of this interpretation and the limestone beds that Weed called Yogo limestone are probably of Devonian age.

The work of Sloss and Laird (1947, p. 1407–1409) and Lochman (1950) has indicated that Weed's type Dry Creek shale occurs, at least in part, above a pre-Devonian unconformity and that it is therefore partly, and perhaps wholly Devonian age. Lochman (1950, fig. 2) called these beds the Maywood formation, a term introduced by Emmons and Calkins (1913, p. 64–65) for strata in the Phillipsburg area in western Montana. In the general area of Three Forks, beds that Lochman considered to be the stratigraphic correlatives of Weed's Dry Creek (the Maywood formation) overlie either Peale's Dry Creek shale or Pebbly limestone. Lochman suggested that the unit first called Dry Creek shale by Peale be considered a member of Dorf and Lochman's (1940) Snowy Range formation and that Peale's Pebbly limestone beds become the Sage pebble-conglomerate member of their Snowy Range formation.

The formation names used in this report are the Pilgrim limestone, Snowy Range formation, and Grove Creek formation. The reasons for their selection are discussed under the formation descriptions that follow.

Section of Upper Cambrian and Upper Ordovician series between head of Rough Draw and crest of Shell Mountain, all in or near SE¼ sec. 21, T. 3 S., R. 11 E. (unsurveyed), Park County, Mont.

	Feet
Bighorn dolomite: Light-gray massive dolomite.	
Grove Creek formation:	
Limestone and shale; gray dense and crystalline limestone interbedded with green shale; stringers of sandstone and siltstone in unit. Limestone occurs as flat-pebble conglomerate and in rounded pebbles; weathers brownish gray in upper few feet. Unit is about half limestone	50
Total Grove Creek formation	50
Snowy Range formation:	
Shale and limestone; shale largely concealed; exposed shale is greenish gray. Limestone in ledges is crystalline (fragmental?) glauconitic limestone	106
Limestone, light-gray; weathers gray to bluish gray; all but lower few feet is in form of columns. Lower 8 feet is thin-bedded flat-pebble conglomerate	33
Shale, greenish-gray; few thin beds of flat-pebble limestone at base	36
Total Snowy Range formation	175
Pilgrim limestone:	
Limestone, mottled light-yellowish- and brownish-gray, finely crystalline, thin- to thick-bedded, cliff-forming. Much is oolitic. Thin stringers of sandstone and siltstone common	105
Limestone, gray, finely crystalline; contains sandy streaks. Basal 8 feet is brown. Thickness probably ranges considerably from locality of measured section	24

Section of Upper Cambrian and Upper Ordovician series between head of Rough Draw and crest of Shell Mountain, all in or near SE¼ sec. 21, T. 3 S., R. 11 E. (unsurveyed), Park County, Mont.—Continued

	Feet
Pilgrim limestone—Continued	
Limestone, gray, dense and finely crystalline; much occurs as breccia or edgewise congolmerate. Unit weathers light blue or green and makes basal part of Pilgrim cliff in part of area, but unit is concealed in most places	46
Total Pilgrim limestone	175
Total Upper Cambrian series	400
Park shale: Gray glauconitic limestone and greenish-gray shale.	

PILGRIM LIMESTONE

The Pilgrim limestone is 175 feet thick and crops out as the first cliff-forming unit above the pre-Cambrian rocks. The lower member is 70 feet thick and is commonly concealed by talus from the cliff-forming upper part. The basal 46 feet is a flat-pebble and edgewise conglomerate composed of gray dense and finely crystalline limestone. The limestone strata have been so broken that much of the edgewise conglomerate is best described as a breccia. This unit weathers light blue or green and is a lighter shade than the overlying limestone. (See figure 61.) This basal unit is seen only in few places.

The upper part of the basal member of the Pilgrim consists of gray finely crystalline limestone that includes many thin sandy streaks and an 8-foot unit of brown limestone at the base. This limestone, like the underlying unit, is not well exposed.

The upper member of the Pilgrim is 105 feet thick near Shell Mountain and consists mostly of light-yellowish-gray partly oolitic limestone that contains many irregularly shaped masses of brown oolitic limestone which are about 1 inch long. Because of the irregular pattern of the light and dark limestones, Walcott (1891) called the unit the "Mottled limestone."

As pointed out in the discussion of the Park shale, the contact between the Park and the Pilgrim limestone is gradational. Dorf and Lochman (1940, p. 550) stated that the limestones in the top of the Park shale contain rounded limestone pebbbles whereas the basal limestones of the Pilgrim contain flat-pebble and edgewise conglomerate. This criteria, if it holds true in the area near Livingston, could not be applied by the writer, partly because the upper part of the Park shale is poorly exposed.

In 1940 Dorf and Lochman proposed that the term Pilgrim limestone be replaced in south-central Montana by the Maurice formation. Their justification for the introduction of new names lies in their statement that lithologic changes of Upper Cambrian strata between

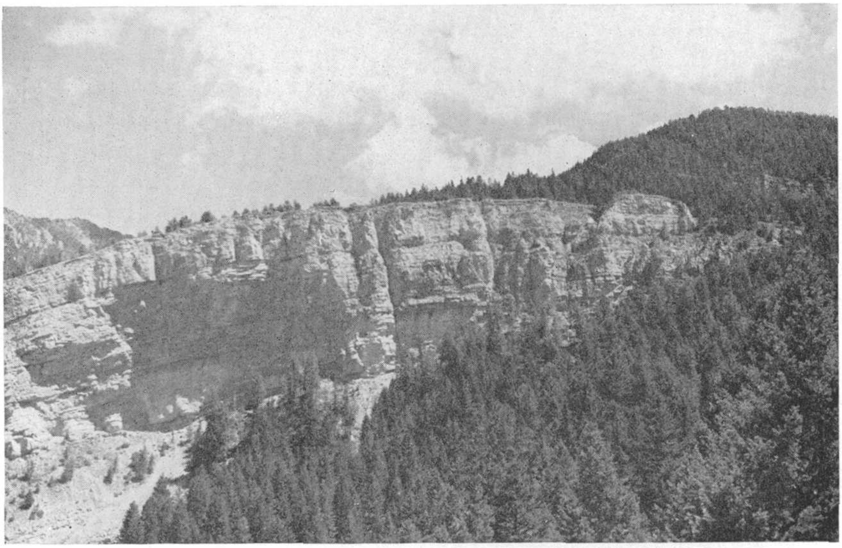

FIGURE 61.—Pilgrim limestone. View eastward along anticline south of Suce Creek.

central and south-central Montana warrant the recognition of these different units (Dorf and Lochman, 1940, p. 542). The Pilgrim in the Beartooth Mountains is mainly mottled oolitic limestone overlying edgewise conglomerate or brecciated limestone. The Pilgrim consists of limestone and shale in the Little Belt Mountains, where the formation was named by Weed (1899 a, b, and 1900). The limestone occurs in massive beds and in beds of flat pebbles. Hanson (1952, p. 16), however, reported the occurrence of beds of oolitic limestone in the Pilgrim in the Little Belt Mountains, and the Pilgrim contains both oolitic and pebbly limestones and shale in the area of Three Forks. In outcrops between these three areas, the Pilgrim contains mottled and flat-pebble limestones. Lochman and Duncan (1944, p. 12) pointed out that the south-central and central Montana sites of deposition were "open" and "contiguous" during Late Cambrian.

The writer concurs with Hanson (1952, p. 16) that—

> It seems best, in the interests of simplified nomenclature, to extend the term Pilgrim to include differing facies so long as these facies have enough in common to distinguish the stratigraphic unit of which they are a part, from subjacent and superjacent units.

It seems to the writer that the "Maurice formation" might be suitably applied to rocks in one or two mountainous uplifts. However, the difficulties of separating the "Maurice" from the Pilgrim limestone where the two interfinger in basins between the outcrops where the formations are named detract so much from the value of a new formational name as to invalidate the use of "Maurice."

SNOWY RANGE AND GROVE CREEK FORMATIONS

The Snowy Range and Grove Creek formations were named by Dorf and Lochman (1940) for strata above the Pilgrim limestone (Maurice formation of Dorf and Lochman) in south-central Montana. The type locality of the Snowy Range formation is about 25 miles south of Livingston near the Snowy Range Ranch on the east fork of Mill Creek, Park County, Mont. The type locality of the Grove Creek formation is along Grove Creek, a tributary to the Clarks Fork of the Yellowstone River along the Beartooth Mountains front 5 miles southeast of Red Lodge, Carbon County, Mont.

Dorf and Lochman reported that the formations are remarkably uniform in thickness and lithology along the Beartooth Mountains, and the sections (p. 397) measured near Shell Mountain support their statement. The two formations were mapped together because their outcrops are so narrow.

The Snowy Range formation is 175 feet thick near Shell Mountain and consists of a lower 36 feet of greenish-gray shale, a middle 33 feet of flat-pebble limestone conglomerate overlain by "columnar" limestone (fig. 62) and an upper 106 feet of inter-bedded poorly exposed greenish-gray shale and light-gray dense and crystalline glauconitic limestone. Of these beds, the lower 34 feet are seemingly the stratigraphic equivalents of Peale's Dry Creek shales (see Lochman, 1950, fig. 1); and the remainder of the formation is in part correlative with and in part younger than Peale's Pebbly limestones (Lochman, 1950, figs. 1 and 2).

The Grove Creek formation is 50 feet thick. It consists predominantly of conglomeratic limestone and shale, but stringers of sandstone and siltstone are common. Many of the greenish-gray limestone pebbles are rounded. These are particularly noticeable among the flat-pebble conglomerates.

At the south base of Elephant Head Mountain 22 feet of Grove Creek strata are well exposed directly beneath the Bighorn dolomite. Of these 22 feet the upper one-half consists of thin platy limestones and a little fissile greenish-gray shale. The limestones weather yellowish gray to brownish gray and most occur as flat-pebble conglomerates. Many thin purple layers in the upper half are highly argillaceous. The uppermost 2 or 3 feet is alternate thin beds of shale and gray dense limestone. Rounded limestone pebbles are not common in the upper half but are abundant in the lower half which is mainly greenish-gray shale and greenish-gray dense flat-pebble limestone conglomerate.

The Snowy Range formation is used herein because of the inconsistencies in the use of Dry Creek shale that have been pointed out by Devonian and Cambrian stratigraphers. The formation in this area apparently includes beds in the stratigraphic position of Peales' Dry

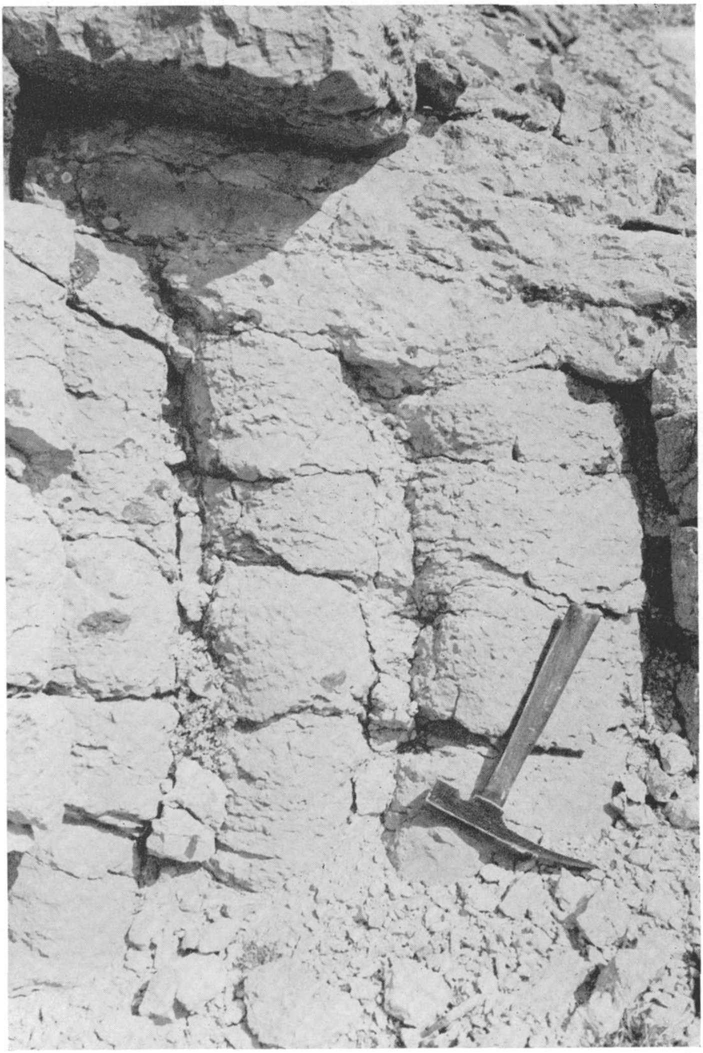

FIGURE 62.—Columnar limestone in Snowy Range formation. Algal (?) limestone in lower part of Snowy Range formation has columnar structure locally.

Creek shales and Pebbly limestones and still younger beds. The work of Dorf and Lochman (1940) and Lochman (1950) indicates that the Grove Creek formation, which is a distinct lithologic unit throughout the Beartooth Mountains uplift, is younger than any Cambrian strata described by Peale or Weed in the Three Forks area and Little Belt Mountains. Its distinctness in both lithology and age merit formational rank for the unit. Both formations are mappable as lithologic units, and their boundaries on the accompanying geologic map represent lithologic changes but not necessarily faunal or age changes.

ORDOVICIAN SYSTEM

BIGHORN DOLOMITE

The Bighorn dolomite near Shell Mountain is 200 feet thick and consists of 155 feet of massive yellowish-gray dolomite at the base, 25 feet of light-gray thin-bedded blocky-weathering dolomite, and, at the top, 20 feet of interbedded dolomite and dolomitic limestone. The massive basal member is readily distinguished in outcrops from the underlying Pilgrim limestone because of the latter's thin bedding (fig. 63), high $CaCO_2$ content, and pronounced mottling of weathered

FIGURE 63.—Bighorn dolomite and Pilgrim limestone. View eastward from southwest slope of Shell Mountain toward West Boulder River beyond dark ridge. The lower member (155 feet thick) of the Bighorn dolomite (Ob-l) and the Pilgrim limestone (Єp) make the upper and lower ledges respectively. The Cambrian Grove Creek (Єg) and Snowy Range (Єs) formations between the ledges and the Cambrian Park shale (Єps) beneath the Pilgrim limestone are largely covered by talus.

surfaces. A change in lithology from beds that are predominantly dolomite to beds of dark-brown and gray sandy and argillaceous limestone marks the contact as herein described of the Bighorn dolomite and the overlying Jefferson limestone. The basal member of the Bighorn is thinner and much less conspicuous in the canyon of the Yellowstone River south of Livingston than it is near Shell Mountain. Ordovician strata have not been described in the area west of Canyon Mountain west of the Yellowstone River.

A section of Bighorn dolomite measured by the writer north of Livingston Peak 4 miles northwest of Shell Mountain is 380 feet thick.

This is nearly twice the thickness of the Bighorn near Shell Mountain but less than the 438 feet of Ordovician strata measured nearby by Tomlinson (1917, fig. 2). The Livingston Peak 7½-minute topographic sheet calls the 9,314-foot peak of pre-Cambrian gneiss Livingston Peak, whereas this peak was referred to by Tomlinson (1917, p. 117), and also is referred to locally as "Old Baldy." The Livingston Peak of Tomlinson's report is the 8,631-foot limestone prominence 1 mile northeast of the gneiss peak. The 380-foot unit (fig. 64)

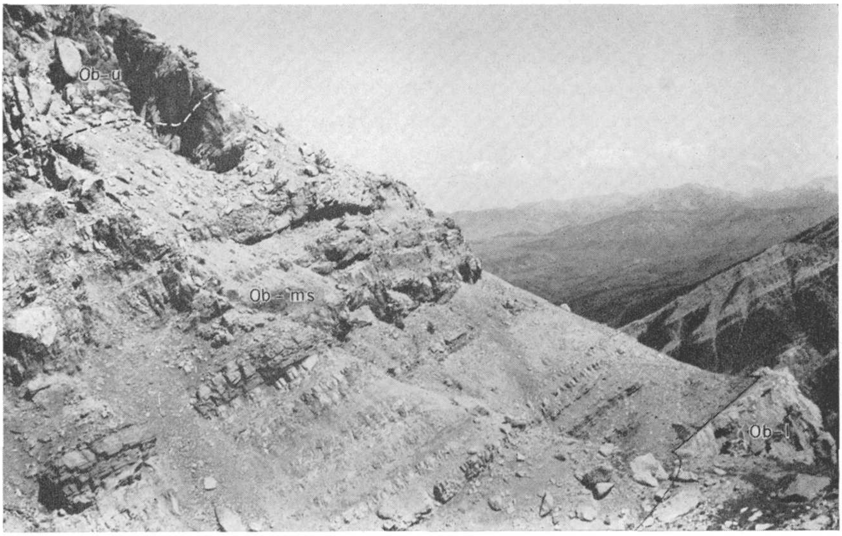

FIGURE 64.—Middle part of Bighorn dolomite near Livingston Peak. View eastward from south slope of peak north of Livingston Peak showing redbed unit of Bighorn dolomite (Ob-ms) between upper (Ob-u) and lower (Ob-l) massive dolomite members.

is divisible into (1) a massive basal member, 120 feet thick (159 feet where measured by Tomlinson), (2) interbedded red, yellow, and gray silty and dolomitic shale, greenish-gray siltstone, and thin beds of limestone and dolomite that total 60 feet, (3) brecciated dark-gray limestones, about 30 feet thick, (4) massive slightly petroliferous dolomite, 140 feet thick, that is slightly darker than the basal member, and (5) light-gray dolomite, about 25 feet thick. No section of similar lithology or thickness was seen elsewhere in the area. Of these five units only the basal dolomite was recognized at Shell Mountain, and the upper four units presumably pinch out along the outcrop eastward and westward from Livingston Peak.

The upper massive member, as well as the basal member are Ordovician; Edwin Kirk (personal communication, November 17, 1950) identified *Receptaculites*, a typical Bighorn fossil collected by the writer from near the middle of the upper massive member. Judging from the difference in thickness of the basal member and overlying variegated beds in sections measured by Tomlinson (1917, fig. 2) and the writer, it seems that the variegated shales and siltstones may lie in one or more channels that were cut into the basal member of the Bighorn. However, inasmuch as the Devonian strata described by Tomlinson (1917, fig. 3) are similar in lithology and thickness to units at Shell Mountain, the extra thickness of Bighorn strata measured by Tomlinson and the writer near Livingston Peak may be partly Devonian strata and partly Bighorn strata repeated by faulting. Thus the topmost 25 feet of light-gray blocky-weathering dolomite and the 140 feet of massive dolomite beneath it may overlie a northward dipping reverse fault and be a repetition of the Bighorn dolomite that lies beneath the varicolored beds. The dark-gray limestone beneath the upper massive dolomite unit closely resembles and may very well be Jefferson limestone, and the underlying varicolored siltstone, shale, and dolomite would then be basal Devonian. The writer believes that the exceptional thickness of the Bighorn in this locality is explained more readily by fault repetition than by sedimentation processes.

The massive member of the Bighorn dolomite in the Bighorn Mountains is generally considered to be Upper Ordovician. The Lander sandstone member (Miller, 1930) in the Wind River Mountains, Wyoming, and the Middle Ordovician Harding sandstone equivalent (Kirk, 1930) in the Bighorn Mountains, both of which underlie the massive dolomite member, have not been found in the area near Livingston. Here the massive dolomite overlies the Upper Cambrian (Trempeleau) Grove Creek formation; therefore, all Lower and Middle Ordovician strata are represented by a hiatus within the mapped area.

DEVONIAN SYSTEM

JEFFERSON LIMESTONE AND THREE FORKS SHALE

The Jefferson limestone is 390 feet thick at Shell Mountain, and Tomlinson (1917, fig. 3) showed 434 feet at the 8,631-foot limestone peak, 1 mile northeast of the point shown as Livingston Peak on the topographic map. Dark-brown argillaceous limestone, in part brecciated and dolomitic, containing thin sandy streaks, make up the lower 230 feet. This is overlain by nearly 90 feet of lighter gray limestone, and it is followed by 70 feet of intensely brecciated limestone, the upper 40 feet of which makes dark ledges.

An 80-foot zone of argillaceous beds above the Jefferson was called the Three Forks formation by Tomlinson (1917, fig. 3). A unit of like thickness at Shell Mountain is mostly concealed but contains shale and argillaceous limestone and dolomite which weather yellowish brown. The unit is herein called the Three Forks shale but was mapped with the Jefferson limestone. Both formations are shown in figure 65. The effects of weathering upon the Three Forks shale is shown in figure 66.

Section of Jefferson limestone and Three Forks shale between head of Rough Draw and crest of Shell Mountain, all in or near SW¼ sec. 21, T. 3 S., R. 11 E. (unsurveyed), Park County, Mont.

	Feet
Madison limestone: Basal part is cliff-forming interbedded limestone and chert.	
Three Forks shale:	
Shale and limestone, largely concealed; thin beds of brown and orange-brown dolomite in upper few feet; basal 10 feet is dolomitic yellowish-gray shale with small ironstone nodules; middle is concealed, weathers to yellowish-brown soil	80
Total Three Forks shale	80
Jefferson limestone:	
Limestone breccia; rock breaks into small fragments but is resistant to erosion and is nearly as prominent in ledges as basal unit of Madison limestone; light to medium gray and dense to finely crystalline	42
Limestone, gray, brecciated, and yellowish- to greenish-gray argillaceous limestone; forms slopes and saddles	30
Limestone, medium-gray, sugary texture, thin-bedded, and platy	36
Limestone; interbedded light-olive-gray dense limestone and yellow and green silty limestone; beds 10 feet below top contain *Atrypa* cf. *A. devoniana* Webster	52
Limestone, brownish-gray; thin yellow silty dolomite bed near base	45
Limestone, brownish-gray, thin- and thick-bedded; thin zone of yellow calcareous shale near base; upper beds contain *Atrypa* and *Coenites*	28
Limestone, brownish-gray, dense, mostly thick-bedded	35
Limestone, gray, dolomitic; interbedded darker gray limestone	30
Limestone, brownish-gray, thin-bedded; weathers to dark surface	22
Limestone, brownish-gray, brecciated	35
Limestone, brownish-gray, thin- to thick-bedded; weathers very dark gray and forms ledges	35
Total Jefferson limestone	390
Bighorn dolomite: Dolomitic limestone and dolomite.	

Both the Jefferson limestone and Three Forks shale were called Upper Devonian by Sloss and Laird (1947, p. 1426). Two small collections of fossils taken from about 175 and 250 feet above the base of the Jefferson limestone were identified by Edwin Kirk (personal communication, February 3, 1950) who stated that the fossils are Middle or Upper Devonian; a more precise determination of age was not possible from the collections.

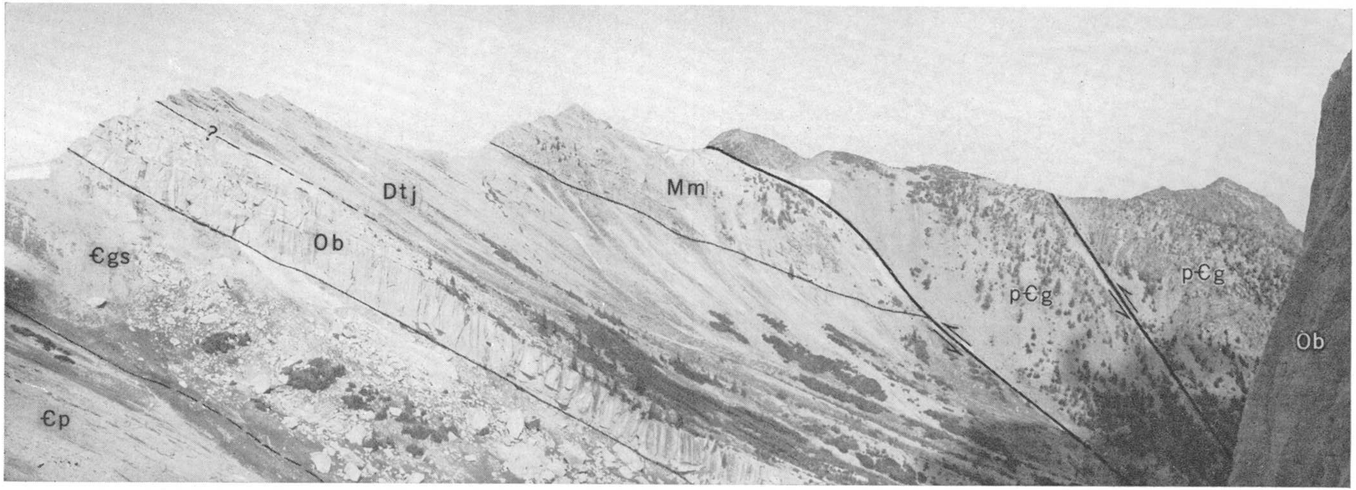

FIGURE 65.—Paleozoic strata south of Suce Creek fault. View westward from south end of Elephant Head Mountain. In descending order; Mm, Madison limestone; Dtj, Three Forks shale and Jefferson limestone; Ob. Bighorn dolomite; €gs, Grove Creek and Snowy Range formations; €p, top of Pilgrim limestone; €pg, pre-Cambrian gneiss. Suce Creek fault is between Paleozoic strata and pre-Cambrian gneiss. A second reverse fault to right of Suce Creek fault is marked by talus along trace of fault plane and by drag in gneiss in hanging wall.

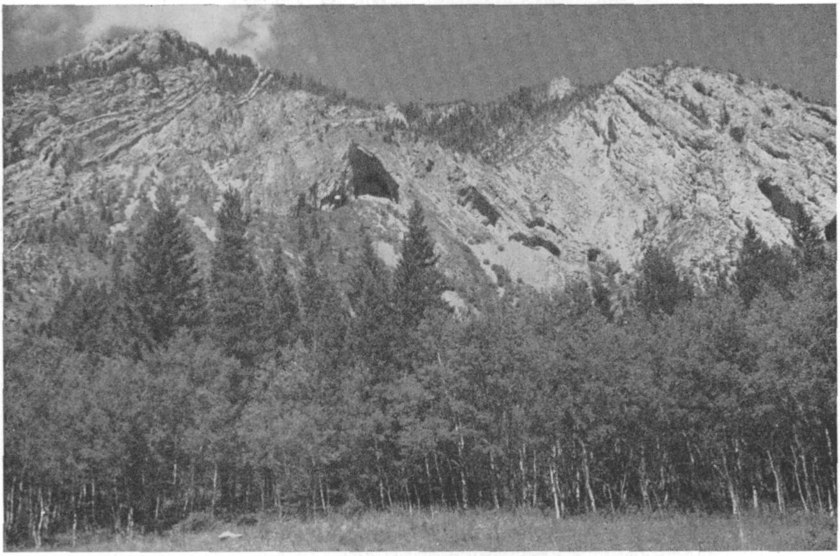

FIGURE 66.—Cave in Three Forks shale along axis of Lion Mountain anticline. View westward from West Boulder Meadows showing cave weathered from the softer shales and siltstones at top of Devonian strata. Cave is about 50 feet high at entrance. Roof of cave is cherty bed of Madison limestone. Most of Madison limestone is exposed to right of cave.

CARBONIFEROUS SYSTEMS

MISSISSIPPIAN SYSTEM

MADISON LIMESTONE

The Madison limestone is 860 feet or more thick at Shell Mountain. Its contact with the overlying Amsden formation lies along the northward-facing slope of Shell Mountain; therefore, a few feet at the top of the formation may not have been included in the measured section. Although the Madison is more than 860 feet thick, this thickness does not approach the 1,500 feet assigned by Iddings and Weed (1894) in the Livingston (1-degree) quadrangle or the 1,800 feet ascribed to the Madison near Livingston by Lammers (1937, p. 270).

The following section was measured on the southwest slopes of Shell Mountain. Fossils listed in the section were collected by the author and were described by Geological Survey paleontologists, the corals by Helen Duncan and the brachiopods by J. S. Williams and Edwin Kirk.

Section of Madison limestone between head of Rough Draw and crest of Shell Mountain, all in or near SW¼ sec. 21, T. 3 S., R. 11 E. (unsurveyed), Park County, Mont.

Madison limestone: (The contact with the Amsden formation is on the dip slope on the north side of Shell Mountain. A few feet of the topmost beds of the Madison limestone that crop out only on the dip slope are not described below.)

	Feet
Limestone, light- to medium-gray, finely crystalline and sugary; contains chert lenses; unit somewhat brecciated, forms ledge and dip slope on top of Madison limestone	62
Limestone breccia, mostly concealed; limestone mostly light to medium gray, finely crystalline; contains a little red silty material which weathers orange	49
Limestone and chert; light-gray finely crystalline limestone and lenses of gray chert; unit weathers gray and forms cliffs locally; some beds in upper part are dark-gray limestone	81
Limestone; upper half massive light-brown sugary limestone, cherty, weathers light gray; lower half mostly concealed. Limestone in upper part gives strong petroleum odor when broken by hammer. Unit is highest topographic point on Shell Mountain.	95
Limestone; yellowish-gray, dolomitic; lower 6 feet slabby dolomitic limestone and upper part somewhat siliceous; chert occurs in nodules and lenses	55
Limestone, light-gray, crystalline, massive; weathers bluish gray and forms cliff; stylolitic; some beds full of crinoid columnal plates	48
Limestone, light-gray, finely crystalline, thin-bedded; thin red argillaceous zones throughout unit; many fragments of crinoid stems in upper 7 feet	25
Limestone, light-gray; in part finely crystalline, massive and thin bedded; forms small ledges; contains *Homalophyllites*?, Caninoid? corals, Clisiophyllid? coral, *Lithostrotion* sp	38
Limestone, light- to medium-gray, finely crystalline; contains a few flat limestone pebbles in base, a few thin stringers of red to purple silty material, and several beds of crinoid fragments	43
Limestone, gray; in part sandy, contains many crinoid columnal fragments and a few thin purple silty or argillaceous stringers	24
Limestone, medium-gray, dense, silty, shaly, and sandy (very fine sand grains); saddle west of highest point of Shell Mountain on this unit; beds in saddle weather yellow and are probably argillaceous. This zone is marked both here and in surrounding area by small, 4 to 6 feet high, algal(?) mounds. Bedding of limestone about reefs is broken	50
Limestone, dense and finely crystalline, and in alternate bands of medium and dark gray; many of lighter gray layers are sandy (very fine grains); thin layers of argillaceous and silty limestone in unit weather gray and yellow; many layers of crinoid stem fragments in unit; topmost 2 feet is composed of limestone and shell fragments that are partly rounded; beds 15 feet below top contain *Schuchertella*? sp. indet., *Chonetes* cf. *C. loganensis* Girty, productid of dictyoclostid-type, *Spirifer centronatus* Winchell, *Punctospirifer* cf. *P. transversus* (McChesney)	108

Section of Madison limestone between head of Rough Draw and crest of Shell Mountain, all in or near SW¼ sec. 21, T. 3 S., R. 11 E. (unsurveyed), Park County, Mont.—Continued

	Feet
Madison limestone—Continued	
Limestone, gray; mostly crystalline, crinoidal, weathers gray, mostly massive and cliff forming	51
Limestone, medium- to dark-gray, dense, thin-bedded; weathers to medium gray; lowermost few feet contain yellow-weathering silty or argillaceous layers; beds 8 feet below top contain *Camarotoechia* cf. *C. herrickiana* Girty; beds near middle contain *Leptaena*? sp. indet., *Schuchertella*? sp. indet., fragmentary mold, *Spirifer* cf. *S. centronatus* Winchell, large var., *Punctospirifer*?, sp. indet., *Composita*? sp. indet., *Dielasma*? sp. indet.; and beds just above lowest yellow-weathering beds contain *Leptaena* cf. *L. analoga* (Phillips), dictyoclostid? fragment, *Camarotoechia* sp. indet., *Rhynchotreta*? cf. *R. elongatum* Weller, *Spirifer centronatus* Winchell, var. indet., *Composita* sp. indet	75
Limestone and chert; gray dense limestone and interbedded gray chert in 2-inch-thick lenses that are as much as 4 feet long. Chert is as much as 40 percent of unit, and the unit is widespread and a very prominent marking horizon	56
Total measured Madison limestone	860
Three Forks shale: Shale and limestone, largely concealed; weathers to yellowish-brown soil.	

The base of the Madison limestone is well marked by 50 feet of cherty thin-bedded limestone beds that weather to a very rough, sharp surface. These basal beds stand in ledges above the easily eroded Three Forks shale. The limestone beds in the Madison are characterized by their light-gray color. Many beds contain abundant crinoid columnals. Several silty layers, notably in the upper part, weather red or purple.

Argillaceous and sandy limestones about 325 feet above the base contain 4- to 6-foot high bioherm like structures of presumed algal origin. The bedding of the enclosing limestone is broken. This unit is well exposed on the south slope of Shell Mountain and below the top of the 8,631-foot limestone peak 1 mile northeast of the gneiss peak shown as Livingston Peak on the topographic map of the Livingston Peak 7½-minute quadrangle.

Extensive erosion dissected the top of the Madison limestone prior to Amsden deposition. Sloss and Hamblin (1942, p. 318) have described red sandstone of Amsden age in solution channels 200 feet below the top of the Madison in the canyon of the Yellowstone River south of Livingston. The contact of the two formations is exposed in very few other places, and little is known regarding the effect of the pre-Amsden erosion upon the Madison.

MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS

AMSDEN FORMATION

The Amsden formation, which is the lower part of the Quadrant formation mapped by Iddings and Weed (1894), is poorly exposed along the northern front of the Beartooth Mountains. It ranges in thickness, from 111 feet at the Yellowstone River canyon south of Livingston (Gardner and others, 1946, p. 72) to 300 feet in the northeast corner of sec. 25, T. 2 S., R. 10 E. In the SE¼ sec. 35, T. 2 S., R. 10 E. along the north side of Dry Creek the Amsden is 140 feet thick.

Locally, as along Dry Creek, the Amsden is divisible into a lower unit of siltstone, shale, and limestone, a middle unit of thin limestone beds, and an upper unit composed largely of siltstone beds that are at least partly red. In some places the Amsden is difficult to recognize as a separate unit. For example, the limestone in the southeastern part of sec. 36, T. 2 S., R. 9 E. looks like Madison limestone but seems to lie, presumably unfaulted, above the basal strata of the Amsden that can be traced westward to the Yellowstone River. The contact between the Amsden formation and the Madison limestone is evidently very irregular, owing to the erosion of the Madison limestone prior to or accompanying deposition of the Amsden formation.

The Amsden formation in the Pryor Mountains and the Bighorn Mountains near the Montana-Wyoming border is in large part Pennsylvanian in age. Fusulinids collected from near the middle of the Amsden in those areas were identified by L. G. Henbest of the Geological Survey (personal communication, 1953) as being of probable Atoka (early middle Pennsylvanian) age. The precise age of the Amsden formation of the Livingston area is unknown, but it is probably close to that of the Amsden in the Pryor Mountains.

PENNSYLVANIAN SYSTEM

QUADRANT QUARTZITE

The Quadrant quartzite as herein described (also by Gardner and others, 1946, p. 72) is the upper massive quartzite member of the Quadrant quartzite mapped by Iddings and Weed (1894) in the Livingston quadrangle. The Quadrant is 100 feet thick and forms a persistent sequence of quartzite and sandstone lying conformably upon the Amsden formation. It is a correlative of the Tensleep sandstone in the Bighorn Basin, Wyoming, and is of Pennsylvanian age.

JURASSIC SYSTEM

The Jurassic system in the mapped area includes marine and continental Middle and Upper Jurassic rocks. It is represented by the marine Ellis group and the continental Morrison formation, each of which is about 400 feet thick. Three formations, the Piper, Rierdon, and Swift, make up the Ellis group. The Piper is Middle Jurassic, and the Rierdon and Swift formations and the overlying Morrison formation are Late Jurassic. The following description of the group was made from the outcrops along Dry Creek ridge southeast of Livingston.

Section of Ellis group on south slope of Dry Creek ridge near the southeast corner of sec. 26, T. 2 S., R. 10 E., Park County, Mont.

	Feet
Morrison formation: Red soil.	
Ellis group:	
Swift formation:	
Sandstone, light-gray, mostly medium-grained, calcareous, glauconitic, crossbedded, brown-weathering; forms ledges; many *Gryphaea* shells in several beds	80
Total Swift formation	80
Rierdon formation:	
Concealed; olive-gray shale and a little siltstone found by digging	87
Limestone, gray, oolitic; weathers light gray, forms ledges, somewhat crossbedded	8
Total Rierdon formation	95
Piper formation:	
Concealed; soil is red	98
Limestone and shale; gray dense partly fossiliferous limestone and brownish- and yellowish-gray shale	26
Limestone; mostly gray platy dense limestone; fossiliferous zone 10 feet below top; unit not well exposed, may include some shale and siltstone	37
Concealed; digging reveals calcareous greenish-gray shale and thin dense gray limestone beds in lower part and reddish- and greenish-gray calcareous shale in upper part; part of shale in upper one-half may be silty	73
Conglomerate; angular chert pebbles as much as 1 inch in diameter in calcareous sandstone like underlying unit	1
Sandstone, yellowish-gray; probably reworked Quadrant quartzite	5
Total Piper formation	240
Total Ellis group	415
Quadrant quartzite: Yellowish-gray quartzite.	

MIDDLE JURASSIC SERIES

PIPER FORMATION

The Piper formation, which is 240 feet thick on Dry Creek ridge and 297 feet thick (Imlay and others, 1948) at the mouth of the lower canyon of the Yellowstone River south of Livingston, lies unconformably upon the Quadrant quartzite of Pennsylvanian age. At Dry Creek ridge the Piper consists of a basal sandstone and conglomerate 6 feet thick, shale and probably some siltstone 73 feet thick, fossiliferous limestone and shale 63 feet thick, and an upper unit that is nearly 100 feet thick and seems to be largely red and green calcareous shale, though it is largely concealed. There seems to be no gypsum, which is typical of the Piper formation farther east, and if there are thin beds within the formation the gypsum has been leached from the outcrops.

An erosional, but nearly parallel, unconformity separates the Piper from the underlying Quadrant quartzite. The basal 5 feet of sandstone in the Piper at Dry Creek ridge is presumably reworked sandstone of the Quadrant quartzite. Although the unconformity truncates progressively older rocks from south to north, it does so at such a low angle that no angular discordance is observable. Forty miles south of Livingston near Gardiner, Mont., the Piper overlies the Triassic Chugwater formation. None of the 137 feet of Chugwater and 167 feet of the underlying Permian Phosphoria formations near Gardiner (Wilson, 1934, p. 652) is found near Livingston. In the Sweetgrass arch about 250 miles north of Livingston the Sawtooth formation (Piper equivalent) lies upon limestone of Mississippian age (Imlay and others, 1948).

Although the Piper formation appears to consist predominantly of marine shale and limestone beds at Dry Creek ridge, it contains considerable amounts of red siltstone at the mouth of the canyon of the Yellowstone River south of Livingston. The formation in the longitude of Livingston includes normal marine strata of the Sawtooth formation of western Montana and redbeds of the eastern Montana Piper formation (Imlay and others, 1948), and, for convenience, the rocks in the mapped area are called Piper.

UPPER JURASSIC SERIES

RIERDON FORMATION

The marine Rierdon formation is 95 feet thick and consists of a basal gray oolitic limestone, 8 feet thick, and calcareous gray to olive-gray shale. Most of the shale is concealed between the ledges of the oolitic limestone and sandstone ledges of the overlying Swift formation. Imlay (Imlay and others, 1948) describes a gradational contact between the Piper and Rierdon formations.

SWIFT FORMATION

The Swift formation, which is about 80 feet thick, is a ledge-forming calcareous sandstone that crops out in ledges or ridges along most of the mountain front. The sandstone is mostly medium grained with many dark mineral grains that give a "salt-and-pepper" appearance to the rock. Most beds are crossbedded, very calcareous, fossilferous, and glauconitic.

Although the Swift seems to be conformable with the Rierdon formation, a pronounced unconformity separates the Swift from underlying formations in central Montana (Imlay and others, 1948). The shale above the basal oolitic limestone is completely cut out by the unconformity in the area between Livingston and the outcrops along the northern edge of the Three Forks quadrangle north of Manhattan, Mont., about 50 miles northwest of Livingston, for in the latter area the Swift formation rests upon the basal oolitic limestone of the Rierdon. Southward from Livingston, however, the Rierdon changes little in thickness, being 81 feet thick near Gardiner (Imlay and others, 1948).

MORRISON FORMATION

The continental mudstones and sandstones of the Morrison formation, which is about 400 feet thick, lie upon the sandstone of the Swift with apparent conformity. Most of the Morrison is covered by soil and talus. The soil above the lower part is red, and in most localities three or four lenses of yellowish-gray sandstone stand in low ledges.

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

KOOTENAI FORMATION

The Kootenai formation, which is more than 300 feet thick throughout the area, consists of a basal chert-pebble conglomerate overlain by continental reddish- to yellowish-gray mudstones and sandstones. The conglomerate forms ridges along the mountain front whereas the overlying beds are poorly exposed. The basal conglomerate ranges considerably in thickness. It is at least 8 feet thick along the south slope of Dry Creek ridge, 25 feet thick near the southwest corner of sec. 23, T. 3 S., R. 11 E., and 25 feet near the mouth of the canyon of the Yellowstone River south of Livingston. Most of the pebbles in the conglomerate are gray chert and are as much as 1½ inches long. The base of the conglomerate is assumed to represent the base of the Cretaceous deposits.

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LOWER AND UPPER CRETACEOUS SERIES

COLORADO SHALE

The name Colorado shale has been used in parts of Montana for the thick predominantly shale sequence that lies above the Kootenai formation and, in most places, below the Virgelle sandstone or Eagle sandstone. Where the Telegraph Creek formation is identified beneath the Virgelle or Eagle sandstones, the Colorado shale underlies the Telegraph Creek (Cobban and Reeside, 1952a, chart 10b). The Colorado shale, which includes sandstone, particularly in west-central Montana, contains both Lower and Upper Cretaceous strata; its vertical range therefore does not coincide with the Upper Cretaceous Colorado group.

Cobban (1951) compared the Colorado shale of central Montana with equivalent rocks in the Black Hills area. From his study it is evident that some formational names of the Black Hills can be used as members of the Colorado shale in central Montana. Some formation names in use in the Bighorn Basin, Wyoming, are not common to the Black Hills and central Montana areas but have been used around the Pryor Mountains and the Bighorn Mountains in south-central Montana. Throughout the following discussion units of the Colorado shale are compared, where possible, with named units in central Montana or the Bighorn Basin. The Colorado shale was measured in part along West Boulder River and in part along Boulder River a short distance east of the Mount Rae quadrangle. These locations are further described in the stratigraphic column (pl. 36).

The Colorado shale along Boulder and West Boulder Rivers is 3,100 feet thick and consists of gray shale and sandstone. Although more sandstone than shale crops out, most of the formation is probably shale. The formation is, however, much more sandy than the equivalent formations farther east (see Richards and Rogers, 1951). Reeside (1944) has indicated that Livingston is less than 200 miles east of the west edge of the Rocky Mountains–Great Plains Cretaceous deposits.

For convenience of discussion, the Colorado shale is divided into 10 units, and these are compared, where possible, with the Black Hills and central Montana or Bighorn Basin formations.

(1) The basal 30 feet is gray marine shale that overlies the sandstone and mudstone of the Kootenai formation. Although the shale was seen only near the West Boulder River it may occur elsewhere but is concealed beneath soil and grass cover.

(2) Thin-bedded flaggy sandstone about 30 feet thick makes low ridges along the mountain flank. The sandstone beds are very fine grained and variably silty and shaly. Bedding planes have abundant trails and other "bottom markings." The unit is similar to the "First

Cat Creek sand" in central Montana and the Fall River sandstone of the Black Hills (Cobban, 1951, p. 2173–2175). It may be essentially equivalent to the Greybull sandstone member of the Cloverly formation in the Bighorn Basin.

(3) The 285 feet of beds above the flaggy sandstone is presumably mostly shale, although the lower 100 feet is well covered by talus and soil. A thin ledge-forming sandstone about 40 feet below the top contains *Lingula*. Other exposed strata are gray shale. This unit is at least in part correlative with the Skull Creek shale of the Black Hills (Cobban, 1951, p. 2175–2176).

(4) A light-gray to white sandstone 20 feet thick makes a conspicuous white ledge in the few places that it is exposed. Most of the sandstone is medium to fine grained and friable. The sandstone is in about the stratigraphic position of the Muddy sandstone member of the Thermopolis shale in the Bighorn Basin and the Newcastle sandstone of the Black Hills area.

(5) The light-gray sandstone is overlain by 330 feet of gray shale. The shale includes several bentonite beds, most of which are only a few inches thick. It is slightly sandy in the lower part, and sand is abundant in thin layers and stringers in the upper 160 feet. The unit is well exposed west of West Boulder River but not elsewhere. These bentonitic and sandy shale beds are largely equivalent to the upper part of the Thermopolis shale in the Bighorn Basin.

(6) The overlying shale, which is 115 feet thick, is a little more sandy. The middle one-third is perhaps more than half fine-grained sandstone. Several thin beds of siliceous sandstone or siltstone resemble the Mowry shale. Siliceous concretions in these beds contain ammonites that were collected and tentatively identified by Cobban and Reeside (personal communication) as *Neogastroplites*, which is characteristic of the Mowry shale (Cobban and Reeside, 1951, p. 1892–1893; Cobban, 1951, fig. 2).

(7) The above-described 755 feet of shale and sandy shale in the third through sixth units that overlies the flaggy sandstones near the base of the Colorado shale have little resistance to erosion and, for the most part, are well concealed. A thick-bedded or massive sandstone above these shale layers is resistant and forms cliffs and ridges. It is 100 feet or less thick and its base serves as the contour horizon for the structure contour map. Owing to its prominence and usefulness as a marker bed the sandstone is herein named the Boulder River sandstone member of the Colorado shale.

The Boulder River sandstone member is 100 feet thick in the SE¼ sec. 11, T. 3 S., R. 12 E. in the McLeod Basin quadrangle along the west side of the Boulder River valley. The member forms an almost continuous ridge from Boulder River westward to the Yellowstone

River south of Livingston. It very likely constitutes one of the sandstone ridges along the north flank of the Gallatin Range south of Coke Creek west of Livingston.

The member crops out on the south slope of a hill west of West Boulder River in the NE¼ (unsurveyed) sec. 26, T. 3 S., R. 11 E., Park County, Mont. The hill is marked on the Mount Rae quadrangle map by an altitude of 6,763 feet. Here the member is about 65 feet thick and consists of gray to yellowish-brown mostly fine-grained sandstone. Above it, and below the crest of the hill, are 145 feet of thin-bedded, in part shaly, sandstone.

The presence of ammonites of Mowry age in siliceous beds below the Boulder River sandstone member and the siliceous beds above suggest that the member may be of Mowry (Albian) age and older than the Frontier formation in and near the Bighorn Basin in Wyoming. See, for example, the discussion of Cobban and Reeside (1952b, p. 1961) on the Big Elk sandstone member of the Colorado shale near Harlowton in central Montana. The Big Elk sandstone member, like the Boulder River sandstone member, lies above siliceous beds that contain characteristic ammonites of Mowry age and below siliceous beds of undetermined age.

(8) Overlying the Boulder River sandstone member is nearly 290 feet of thin-bedded sandstone that contains many layers of chert pebbles. These beds are well exposed in the Boulder River valley in sec. 11, T. 3 S., R. 11 E. but are only partially exposed elsewhere. A chert-pebble conglomerate of this unit that is exposed east of the Yellowstone River near the mouth of the canyon of the Yellowstone River appears to be much like the basal conglomerate of the Kootenai formation.

Several beds of siliceous shale and sandstone in the unit weather bluish gray, similar to siliceous beds of the Mowry shale in the Bighorn Basin. Other shale is black, very hard, and probably highly siliceous, too. This unit, therefore, possesses physical characteristics of both the Frontier formation and the Mowry shale. Chert pebbles are typical of the Frontier formation, where as siliceous beds are characteristic of the Mowry shale (Rubey, 1929).

(9) The 255 feet of sandstone and shale overlying units 7 and 8 were measured in the Boulder River valley in the same locality that the Boulder River sandstone member was measured. These beds are concealed in the West Boulder River section. The lower 100 feet of this unit is predominantly shale with thin-bedded calcareous sandstone. A friable sandstone near the base contains chert pebbles that are as much as 1 inch in diameter. Chert pebbles also occur in soil near the top of this 100-foot unit. The upper 155 feet includes thin-

bedded to massive gray to brown sandstone that is ledge forming locally.

(10) The upper part of the Colorado shale was measured along West Boulder River. Most of the section is grass covered, and only ledges of sandstone and a little shale are exposed. The unit is at least 1,500 feet but probably not more than 1,650 feet thick. Cobban and Reeside collected *Scaphites ventricosus*, an ammonite of middle Niobrara age, from shale nearly 800 feet above the top of the Boulder River member, or about 250 feet above the base of this unit. This shale of Niobrara age is exposed on the north side of a gully near the west edge and about 900 feet south of the north border of sec. 25, T. 3 S., R. 11 E. The fossils were collected from near the top of the slope.

Near Livingston, on the east bank of the Yellowstone River the upper part of the Colorado shale is very sandy. Thin-bedded sandstone and dark-gray shale underlie the Virgelle sandstone, which crops out between the airfield and the Yellowstone River bridge east of Livingston. These sandy shale beds are at least 450 feet thick, and perhaps considerably more. Cobban collected an ammonite of upper Niobrara age *Clioscaphites choteauensis* from this unit 425 feet below the Virgelle sandstone. Lithologically similar beds that lie between the shale of Niobrara age and the Virgelle sandstone—or Eagle sandstone—in central and south-central Montana are called the Telegraph Creek formation (Cobban, 1951, p. 2195, Richards and Rogers, 1951). The Telegraph Creek formation, however, contains higher faunal zones in these more easterly areas than that of which *Clioscaphites choteauensis* is indicative (Cobban and Reeside, 1952a, chart 10b). Although the equivalent lithologic unit of the Telegraph Creek formation is recognized within the mapped area, the beds are so poorly exposed that their base could not be followed, and the unit has been mapped with the Colorado shale.

The shale of Niobrara age, thickens westward from 200 feet north of the Bighorn Mountains to 635 feet on the Kevin-Sunburst dome in northwestern Montana and has been described by Cobban (1951, p. 2192–2193). The rocks of Niobrara age which are more than 1,000 feet between the beds containing *Scaphites ventricosus* and *Clioscaphites choteauensis* in the Livingston area thus appear to be exceptionally thick.

UPPER CRETACEOUS SERIES

VIRGELLE SANDSTONE AND UNDIVIDED YOUNGER STRATA

The Eagle sandstone in central Montana overlies the Colorado shale, or where recognized, the Telegraph Creek formation. In outcrops along the Yellowstone River near Billings, Mont., and along the

Missouri River south of the Bearpaw Mountains the Eagle consists of three units: a basal sandstone member (the Virgelle member) a middle carbonaceous unit that locally contains coal, and an upper sandstone unit. The Virgelle sandstone is distinguished in northwestern and north-central Montana as a formation that lies above the Colorado shale, or Telegraph Creek formation, and below continental strata called the Two Medicine formation (Stebinger, 1914, p. 62–63).

The threefold nature of the Eagle sandstone is not readily recognizable throughout the Livingston area. The Virgelle sandstone is traceable along the northern front of the Beartooth Mountains. At the old town of Cokedale, about 7 miles west of Livingston, beds above the Virgelle contain coking coal, which was mined during the first of the century, and interbedded gray sandstone and tuffaceous sandstone occur above the coal zones. Other coal beds have been prospected or mined in Coal Mine Mountain south of McLeod in the McLeod Basin quadrangle just east of the mapped area. A little coal was mined from beds that may be at about the same stratigraphic level but which are included with the Livingston formation on the geologic map in the NW¼ sec. 19, T. 2 S., R. 11 E. near Mission Creek.

Above the coal-bearing strata is a sequence of gray sandstone and dark-gray shale that grades upwards into the Livingston formation. The unit is about 1,300 feet thick along the West Boulder River in sec. 24, T. 3 S., R. 11 E. and less than 100 feet along the Yellowstone River just east of Livingston. The thick sequence in sec. 24 is well covered except for the gray sandstone, and the concealed beds are thought, judging from spotty outcrops, to be mostly gray shale. The thinner section of gray marine shale and associated sandstone between the Virgelle sandstone and the Livingston formation near Livingston seems most likely to be due to the deposition of tuffaceous beds of the Livingston formation a little earlier there than at the West Boulder River locality.

The above described strata are presumably correlative with the Eagle sandstone and Claggett shale, but those formation units cannot be differentiated here. The map of Parsons (1942, fig. 2) indicates the presence of the Eagle sandstone and Claggett shale beneath the "Livingston igneous series" north of McLeod in the northeastern part of T. 2 S., R. 13 E. Those beds, however, are part of the tuffaceous strata in the lower part of the Livingston formation as mapped by Weed (1893, pl. 1) and by the writer. Although the beds may be of the same age as the Eagle sandstone and Claggett shale farther east the lithology is largely that of the Livingston formation.

The Virgelle sandstone is partially covered near West Boulder River but is about 100 feet thick. It crops out in a conspicuous ledge between the Yellowstone River and the airfield east of Livingston. Between these two localities the Virgelle ranges considerably in thickness and is not different in appearance from other gray sandstone in the Colorado shale, except that on the east side of Mission Creek it weathers to a very light gray which is characteristic of the Virgelle sandstone in many localities in west-central Montana.

UPPER CRETACEOUS SERIES AND TERTIARY SYSTEM

LIVINGSTON FORMATION

Weed (1893) applied the name Livingston formation to the thick sequence of tuffaceous strata exposed near the town of Livingston. Hayden had observed these beds as early as 1871 (Hayden, 1872) and Lindgren (1886) mentioned them in 1886, but Weed was the first to describe the formation in considerable detail. Stone and Calvert (1910) had worked out the general stratigraphic relationship of the formation in the Crazy Mountains syncline.

The Livingston formation was divided into three members by Weed (1893, p. 21–31): (1) the lower "leaf beds" consisting of sandstone, conglomerate, and shale composed "largely of angular or but slightly water-worn debris of volcanic eruptions and ash showers," (2) a middle unit of "volcanic agglomerate," described as consolidated volcanic ejectamenta that rests upon the lower beds of the Livingston formation and thins westward from the area drained by the Boulder River, and (3) the "Livingston conglomerate," the shale and sandstone that contain nonvolcanic pebbles in conglomerate layers.

Weed thought that the upper beds, which were described as gray crossbedded sandstone, gray shale, and lenses of limestone, were probably the Fort Union formation. A younger age for the fossils in the upper beds was also noted by Weed (1893, p. 35). The rocks of Paleocene age (Fort Union) were included with the Livingston formation by Iddings and Weed (1894); however, the Livingston formation is considered by the Geological Survey to be both Cretaceous and Tertiary in age (Wilmarth, 1938, p. 1201). Brown (1949) mapped the contact between Cretaceous and Paleocene rocks (Fort Union) in the Crazy Mountains syncline, and he referred to the Paleocene rocks as "part of the Livingston formation." The rocks of Paleocene age as mapped by Brown are north of the area mapped for this report.

Folding and faulting within the area make accurate measurements of the Livingston formation difficult. Based upon measurements in three localities shown in the stratigraphic column, the Livingston exposed within the mapped area is estimated to be about 7,000 feet thick. This includes the lower part of Weed's Livingston conglomerates. The uppermost zone of the formation in the Livingston Peak quadrangle was traced on aerial photos westward into a uniformly striking, northward-dipping sequence north of Cokedale which is about 7 miles west of Livingston. The part of the Livingston formation between this horizon and the base near Cokedale is 8,000 feet thick. The combined thickness of the Livingston and the underlying strata to the base of the Virgelle sandstone is about 9,000 feet north of Cokedale and between 8,500 feet and 9,000 feet east of Livingston. As the beds above the Virgelle sandstone and beneath the Livingston formation thin from about 1,330 feet from West Boulder River to about 100 feet east of Livingston, the overall thickness of the strata from the base of the Virgelle sandstone to the uppermost mapped zone of the Livingston formation within the area seems to be nearly uniform between Cokedale and the West Boulder River. Because of difficulties in measuring the strata, the figures given for thicknesses may be in error by 10 percent or possibly more.

This range in thickness of the beds above the Virgelle sandstone represents the interfingering of tuffaceous and nontuffaceous beds. The base of the Livingston formation is difficult to delineate; the lower contact represents, as could best be determined, the change from predominantly nonvolcanic debris to predominantly volcanic debris in the Livingston formation.

The Livingston formation within this area may be divided into five units, but there are no sharp contacts between them. The lower 900 feet along the east side of the Livingston Peak quadrangle is made up mostly of brown and green, with some blue tuffs. They are fine to coarse grained, and some layers contain abundant leaf impressions. The lower part of this unit is very well exposed in Mission Creek syncline, and the basal part makes a blue escarpment in the syncline on the west side of West Boulder River. Two 50-foot beds of yellowish-gray tuffs containing large dark-brown round concretions occur at the top of this unit. The two beds with these "cannon ball" concretions occur above a zone of dark-brown tuff and are separated by a few feet of nonconcretionary tuff. The concretions are particularly well exposed north and south of the Yellowstone River less than 1 mile east of the Elton 7½ minute quadrangle.

The concretions crop out on the southwest flank of Hunters anticline in sec. 35, T. 1 S., R. 11 E. and south of the Yellowstone River along the fault in the NE¼ sec. 2, T. 2. S., R. 11 E. Similar concretions occur locally, but sparsely, in other beds of tuff, and the identity of the two concretion beds as a marker horizon disappears west of Mission Creek. Carbonaceous shale occurs locally beneath the concretion beds around Hunters anticline. A line has been drawn on the map showing the base of the concretion zone east of the longitude of Mission Creek.

A wedge of coarse volcanic conglomerate and breccia (Weed's agglomerate member) overlies the concretions south of Springdale, which is a small settlement in the Yellowstone River valley 1 mile east of the area. This unit thickens southeastward from Springdale and is offset westward just north of the Yellowstone River by the Greeley fault. Parsons and Stow (1942) have described the source of the material as vents along the front of the Beartooth Mountains southeast of Springdale. Although no thick section of the volcanic conglomerate and breccia appears north of the Yellowstone River in outcrop, thin beds of breccia, or conglomerate, of volcanic rocks occur above the concretion zone around Hunters anticline. These thin beds undoubtedly represent the more northwesterly deposits of the so-called Livingston agglomerate or igneous member.

About 1,000 feet of greenish- and yellowish-gray tuff overlies the breccia. These beds are much like the tuff in the lowest unit of the Livingston, and the two units cannot be separated in areas where the breccia zone is absent. Above the tuff beds are about 2,000 feet of gray to yellowish-gray tuff and tuffaceous sandstone and interbedded gray to reddish-gray shale. The shale is conspicuous along U. S. Highway 10 west of Livingston, south of U. S. Highway 10 west of Mission station of the Northern Pacific Railway opposite the mouth of the Shields River, and along the county road west of Hunters anticline north of the Yellowstone River. Part, and perhaps all, of the red color of the shale comes from oxidization during weathering.

The uppermost 3,000 feet of the formation within the area is exposed in the northern part of the Mission and Elton quadrangles. This is a series of gray tuff, tuffaceous sandstone, shale—some of which weather reddish gray—and a few thin beds of conglomerate that contain pebbles of chert, limestone, quartzite, and volcanic rock. Chert is the most abundant constituent of the conglomerate. Most of the limestone and chert were derived from Paleozoic formations. The conglomerate is coarser and thicker along the east flank of the Bridger Range (Weed, 1893, pl. 4) than in the mapped area; hence, the source of the conglomerate must have been largely or wholly from the Bridger Range or even farther west.

The volcanic origin of much of the material in the rocks of the Livingston formation has been discussed by Weed (1893) and Stone and Calvert (1910). A few samples collected by the writer in 1949 were examined by Robert L. Smith of the Geological Survey. The majority of the samples described in the literature, as well as those examined by Smith, are andesitic crystal tuff and sedimentary tuff. Smith noted a strong alteration of the mineral grains and abundant zeolitic material cementing the grains. Most of the samples that have been examined microscopically and described in the literature very likely had been selected to illustrate the pyroclastic origin of the material in the beds, but detrital quartz and fragments of metamorphic rocks are common to abundant in many of the tuffs.

Subaerial and subaqueous deposits are interbedded in the Livingston, the latter type seemingly predominant. Fresh-water and brackish-water mollusks (Weed, 1893, p. 33), good leaf impressions, and one known collection of marine invertebrates (Stone and Calvert, 1910, p. 665) give proof that some of the formation was deposited in water. A bed of massive tuff west of the trail in the central part of sec. 23, T. 1 S., R. 11 E. encloses a vertical tree stump. A sample of the tuff was identified by Smith as an andesitic crystal tuff; detrital quartz that is found in many beds of water-deposited tuff was missing. Both the thin section and field examination indicate the bed to be a subaerial accumulation of volcanic ash. No volcanic flows were seen within the quadrangle.

Tuffaceous sandstone and shale, which were described by Wentworth and Williams (1932, p. 41) as rocks containing less than 50 percent volcanic ejectamenta, are difficult to distinguish from the tuff in the field. Many quartz grains that appear rounded when viewed with a hand lens appear under the binocular microscope to be rounded on one side but angular on other sides. The roundness may thus be a feature of the rock's pyroclastic origin rather than being the result of stream abrasion. No bentonite was seen in the Livingston formation, but the reddish-gray shales in the upper part may be bentonitic.

Little has been said of the age of the Livingston formation since the work of Stone and Calvert (1910) other than Brown's map (1949) showing the Upper Cretaceous-Paleocene boundary. McMannis (1955, p. 1408) recently has stated that the red (or purple) shale and associated beds are of Lance (Hell Creek) age. The determination was largely based upon study of vertebrate remains found in and near Bozeman Pass, which is about 12 miles west of Livingston.

QUATERNARY SYSTEM

Except for possibly the upper part of the Livingston formation the only Cenozoic deposits in the mapped area are unconsolidated stream and glacial material and landslide masses, and these are probably Pleistocene and Recent. Alden (1932, pl. 1) shows no surficial deposits older than Pleistocene.

STREAM TERRACES AND VALLEY ALLUVIUM

The valleys of the Yellowstone River and Shields River have broad alluvial floors that include a narrow flood plain and low terraces that rise to nearly 60 feet above river level. These low terraces are, for the most part, so discontinuous that they have been mapped with the alluvium.

Remnants of formerly extensive higher terraces occur along the Shields River and the Yellowstone River; these are the number two and three levels of Alden (1932). Most of the terraces are at one of three general levels—200, 300, and 400 feet above the river. Two small terrace remnants 500 feet above the Yellowstone River on each side of Mission Creek about 2 miles south of U. S. Highway 10 were evidently cut by Mission Creek.

Gravels in the flood plain of the Shields River 2 miles north of the mouth of the river are made up of about 75 percent volcanic rock; the remainder is limestone and sandstone. Most of the gravel is less than 6 inches in diameter, although some boulders are as much as 16 inches across. The Shields River drainage basin includes no metamorphic rocks or granite; the streams traverse Paleozoic to Cretaceous sedimentary rocks. The large volume of igneous rocks in the floodplain gravel presumably comes mostly from dikes and sills in the Crazy Mountains area.

The lithology of the pebbles in the Yellowstone River terraces differs from place to place, reflecting the composition of rocks exposed along the tributary streams. The gravel deposits range from less than 5 feet to more than 30 feet thick. Gravel in a low terrace along U. S. Highway 10 just east of Mission Creek includes the following rock types: (1) Gneiss, about 50 percent of all material between 3 inches and 12 inches in diameter, (2) granite, almost all the few boulders more than 12 inches in diameter, (3) limestone, 25 percent of rock 3 inches to 12 inches in diameter, and (4) sandstone, quartzite, and volcanic rock, 25 percent of rock 3 inches to 12 inches in diameter. A terrace at about the same level along the highway in sec. 28. T, 1 S., R. 12 E. has material similar in lithology to the above described deposit, but volcanic rock makes up about 25 percent of the aggregate—most of which occurs in the place of limestone. Hence, it appears that the greater abundance of limestone in the terrace near the mouth of Mission Creek resulted from the transportation of limestone gravel from its source in the mountains only a few miles to the south.

Gravel in the road cut between the Yellowstone River and the Park County airport east of Livingston is of two ages. The lower layer, which is about 20 feet thick, consists mostly of gneiss and volcanic rocks that are so deeply weathered that they can be disintegrated by two or three hammer blows. No similar deposit was seen elsewhere. The younger gravel overlying this weathered deposit consists mostly of volcanic rocks.

The two small high terraces along Mission Creek in sec. 7, T. 2 S., R. 11 E. contain boulders as much as 5 feet in diameter, 90 percent of which are gneiss. Material below 12 inches in diameter is about 60 percent gneiss and 40 percent limestone, quartzite, and sandstone. Very few volcanic rocks are present. Both size and lithology of the gravel suggest that the gravel was part of the Mission Creek flood plain at a higher level.

MORAINES

Small glaciers existed in most of the canyons in the Beartooth Mountains during the Pleistocene, but only the larger glaceirs pushed beyond the mouths of their canyons. Lateral moraines extend for a mile down Mission Creek from the mouth of the canyon in sec. 5, T. 3 S., R. 11 E. Most of the valley floor of West Boulder River within the quadrangle is a ground moraine with abundant boulders and depressions. Lateral moraines are as high as 800 feet above the river level on the west side of West Boulder River, where they lie on top of the upland slopes in front of the mountains.

Westward-flowing streams, such as Pine Creek, that enter the Yellowstone River south of Livingston have moraines at their canyon mouths. These have been described by Horberg (1940, p. 298).

ALLUVIAL FANS

Alluvial fans extend as pedimentlike deposits from Dry Creek ridge westward and northward to the Yellowstone River and cover the rear edges of several terraces. The material consists mostly of angular fragments of limestone, which range in size from silt particles to boulders as large as 6 feet; however, most of the material is only a few inches in diameter. Pits have been opened in the fans and the material crushed and used for road metal.

LANDSLIDES

Landslides along Mission Creek and along the north flank of Mission Creek anticline have sandstone and shale of the Virgelle sandstone and Colorado shale. Small slides have taken place along the sides of West Boulder River valley where the slopes were steepened during glaciation.

Movement continues slowly in the small slides along Mission Creek in sec. 28, T. 2 S., R. 11 E. The largest mass, which seems to have been part of one slide, covers all of sec. 22, T. 2 S., R. 11 E. and much of the adjacent sections. The mass movement of the Virgelle sandstone and the overlying sandstones and shale seems to be in part caused by high topographic relief and in part by a northward-dipping section of interbedded shale and sandstone along the north flank of Mission Creek anticline, both of which facilitate gravitative slipping.

STRUCTURAL GEOLOGY

GENERAL FEATURES

The area covered by this report includes the northwest corner of the Beartooth Mountains and a sector of the southwest edge of the Crazy Mountains syncline. Sedimentary rocks within much of the mapped area are greatly distorted; many faults and folds in the Crazy Mountains syncline even strike perpendicularly to the mountain front.

The Crazy Mountains syncline is a large northwestward-trending downwarped structural area that lies to the northwest of the better known Bighorn Basin of Wyoming and Montana. The syncline is about 100 miles long and not more than 50 miles wide and is bordered by mountains most of the way from its northwest end around its west side to its southeast end, as illustrated by figure 58. The east side of the syncline is difficult to define, because the syncline merges into the plains area of central Montana. A line of anticlines and domes that extend southeastward from the Little Belt Mountains to to the Pryor Mountains marks, rather arbitrarily, the syncline's east edge.

The boundary between the Crazy Mountains syncline and the Bighorn Basin is also difficult to define. Alpha and Fanshawe (1954, p. 77) stated that the Nye-Bowler lineament is the northern structural boundary of the Bighorn Basin. This lineament, which is essentially a long complexly faulted anticline, was shown by Wilson (1936) to trend generally northwestward 56 miles from the abandoned postoffice of Bowler just west of the Pryor Mountains to the Beartooth Mountains front near Nye, which is near the Stillwater River. Alpha and Fanshawe (1954, p. 77) would extend the lineament 60 miles farther northwestward along the mountain front to Livingston, but their report indicates that the Bighorn Basin as a structural unit pinches out where the lineament converges with the mountain front near Nye. Further discussion of, as well as a definition of, the south edge of the Crazy Mountains syncline is beyond the scope of this report.

Figure 58 shows the relation of the Nye-Bowler lineament defined by Wilson to the Crazy Mountains syncline and the northern part of the Bighorn Basin. The axis of the Crazy Mountains syncline has not been closely determined but seems to lie about as shown in the illustration. The axis of the Bighorn Basin in Wyoming has been shown by Pierce and others (1947), and the northward continuation of the axis into Montana, where it is covered in part by pre-Cambrian and Paleozoic rocks of the Beartooth Mountains overthrusts, has been shown by Fanshawe and Alpha (1954).

Both the Crazy and Castle Mountains in the northwestern part of the Crazy Mountains syncline are composed mainly of Tertiary intrusive igneous rocks, which are complex both structurally and petrographically. Had these igneous bodies never formed and if mountains had formed along the east edge of the syncline, the Crazy Mountains syncline would appear to be similar, superficially at least, to the Bighorn Basin.

The Beartooth Mountains have been discussed by many writers, among them Bevan (1923), Bucher, Thom, and Chamberlin (1934), Wilson (1934), Lammers (1937), and Chamberlin (1945). The mountains trend northwestward from Wyoming into Montana, as a broad, faulted anticlinal structure about 80 miles long and 40 miles wide. They are bordered on the south by the volcanic rocks of the Yellowstone plateau and the Absaroka Range, on the east and north by the Bighorn Basin and the Crazy Mountains syncline, and on the west by the Yellowstone River valley. Most of the central part of the mountains is igneous and pre-Cambrian metamorphic rock. Volcanic rocks of the Yellowstone plateau and the Absaroka Range areas extend northward in irregular outline onto the south edge of the Beartooth Mountains. A patch of the volcanic rocks and some Paleozoic sedimentary rocks occur within the west-central part of the mountains in the Mill Creek drainage basin 25 miles south of Livingston.

East of Stillwater River canyon, the mouth of which is about the midpoint of the north flank of the Beartooth Mountains (see fig. 58), pre-Cambrian and Paleozoic rocks have been thrust eastward and northeastward upon Mesozoic and Tertiary rocks in the Bighorn Basin and the Crazy Mountains syncline. West of Stillwater River canyon, however, the faults along the north edge of the mountains dip steeply northward. Chamberlin (1945) has shown northeastward-trending zones of thrusts and overturned folds crossing the Bighorn Mountains and the Beartooth Mountains. The direction of asymmetry alternates from southwestward to northeastward from one zone to the adjacent zone (Chamberlin, 1945, fig. 1). The Beartooth Mountains west of Stillwater River canyon are in one of these zones in which the folds along the mountain flank have the steeper dip on their southwest side, and faults along the mountain edge dip steeply northeastward.

The Beartooth Mountains were described by Horberg and others (1949) as being part of the depositional platform area east of the main Rocky Mountain geosyncline. Deformation of this foreland, or platform, area is characterized by asymmetrical anticlines that have been broken by high-angle reverse faults and by thrust faults that were formed during a later stage of deformation than the high-angle reverse faults.

The west end of the Beartooth Mountains is outlined by steep northward-dipping faults on the north, a nearly vertical fault on the west, and a northward-dipping thrust (Wilson, 1934) on the south. An eastward-striking fault along Elbow Creek about 25 miles south of Livingston and a second fault along Mill Creek just south of Elbow Creek, divide the mountains into north and south blocks.

The displacement along the Elbow and Mill Creeks fault zone is indicated by the map of Iddings and Weed (1894) to be at least 5,000 feet, the north side having moved upward relative to the south block. Although Iddings and Weed indicated that the Elbow Creek fault, which is the main one of the two faults, dies out west of the headwaters of Boulder River, the Tectonic map of the United States (King, P. B., and others, 1944) shows it to continue eastward to the general longitude of the Stillwater River canyon.

Within the area covered by this report the mountain flank structures are characterized by high-angle normal and reverse faults, strike-slip faults, possibly one low-angle thrust fault, and several faulted anticlines. Similar structures prevail in the plains north of the Beartooth Mountains but the trend of structures in the latter area is nearly perpendicular to the main trend of the mountain folds and faults. In the discussion of these individual structures the names given by Lammers (1937) are used, except that the Dry Creek ridge anticline is herein called the Livingston anticline and other names are somewhat modified for simplicity.

The high-angle, nearly vertical, Deep Creek normal fault (Lammers, 1937; Horberg, 1940; Pardee, 1950) marks the west edge of the north block of the Beartooth Mountains. Its continuation north of the Suce Creek fault is probably the Stumbo Mountain fault, although Lammers (1937, p. 278) considered the fold in the limestone of Paleozoic age north of Suce Creek and east of the Yellowstone River canyon to be the north end of the Deep Creek fault. The trace of the fault has not been shown south of Deep Creek on the accompanying geologic map, but it presumably is covered by surficial material along the edge of the Yellowstone River valley. A second, nearly vertical fault of major displacement, the Lost Creek fault, extends eastward from Davis Creek almost to the Boulder River south of Mount Rae.

The Suce Creek fault is a high-angle reverse fault that extends from Suce Creek southeastward to Davis Creek. Although it may be a low-angle thrust fault along the lower part of Suce Creek, the fault dips as much as 80° northward in the canyons southeast of Livingston Peak. This fault, which has more than 1 mile stratigraphic throw south of Livingston Peak, moved pre-Cambrian gneiss upward into contact with Paleozoic strata as high stratigraphically as the Madison limestone. A somewhat similar reverse fault along Dry Creek has brought the Madison limestone in the Livingston anticline opposite Jurassic rocks. These reverse faults trend parallel to the mountain front, or about northwest. Smaller reverse faults and other faults which seem to be tear faults trend at right angles to the reverse faults.

Between Davis Creek and West Boulder River are the Mount Lion syncline and anticline, which are tightly folded against the Lost Creek fault. The Livingston anticline was "thrust" southward along the Dry Creek fault indicating a close relationship of folding to the mountain flank faulting. Limestone of Paleozoic age east of the Yellowstone River south of Livingston have been folded into a large overturned anticline that overlies the Suce Creek fault. The fold appears as a monocline in the walls of the Yellowstone River canyon, but the fold is overturned southward in sec. 16, T. 3 S., R. 10 E., as can be seen in the cross-sectional view afforded along Suce Creek.

North of and parallel to the mountain front are the long Mission Creek syncline and anticline. These trend northwestward from near Boulder River and die out west of Mission Creek. This same trend is followed by the previously mentioned Livingston anticline, which strikes northwestward through the town of Livingston. Both of these anticlines have a continuous northwesterly plunge.

The Cretaceous strata that dip away from the mountain flank into the Crazy Mountains syncline have been folded and faulted rather severely in the area east of Mission Creek. The trend of the folds and the faults is almost perpendicular to the trend of the mountain-flank structures. The same Cretaceous strata west of Mission Creek trend around the plunging Livingston anticline but are otherwise little affected by folding and faulting.

The faults east of Mission Creek are presumably high angle, although only the Greeley fault is seen in cross-sectional view. Its plane is visible along the north side of the Yellowstone River on the south slope of Buffalo Hump.

Anticlines and synclines north of the mountain flank and east of the longitude of Mission Creek strike about parallel with the associated faults. The folding south of the Yellowstone River is locally very tight and is isoclinal in part of the northeastward-plunging Elton and Greeley anticlines. Hunters anticline north of the Yellowstone River has a faulted east flank, and beds west of the fault are overturned locally. Although the dip of the fault along the east side of the anticline cannot be seen, it probably dips northwestward and passes beneath the anticline. This anticline is the only one within the area with surface structural closure, with the exception of closure against a fault near the northwestern end of the Mission Creek anticline and a probable fault closure on the Livingston anticline.

AGE OF DEFORMATION

The folding of the pre-Cambrian strata was the first period of intense deformation decipherable in the rocks of the mapped area; in places the gneiss and schist were nearly vertical when Middle Cambrian seas covered them. From Cambrian time until late in the Cretaceous or early in the Tertiary the area was alternately subjected to periods of erosion and deposition. During this time the movements were seemingly largely vertical, with little or no horizontal movement that would fold the rocks. The unconformities in the sedimentary section separate strata that are essentially parallel.

During the deposition of the continental Judith River strata throughout central Montana in Late Cretaceous time the north edge of the present Beartooth Mountains was probably land. Deposition of Weed's agglomerate member (the igneous member of Parsons and Stow) in the Livingston formation is considered by Parsons and Stow (1942, p. 345) to have started during Judith River time and to have originated from volcanic centers near the north edge of the present Beartooth Mountains.

Limestone cobbles in younger beds of the Livingston formation are evidence that the area occupied by the present Bridger Range was undergoing erosion by latest Cretaceous or early Tertiary time (Weed, 1893, p. 30–31). Thus a long period of uplift of mountain areas located on about the west and south edges of the Crazy Mountains syncline is indicated.

The youngest strata within the area are latest Cretaceous or early Tertiary in age, and these were seemingly folded along with the older Cretaceous rocks. There is no evidence to indicate that extensive folding took place prior to the orogeny that deformed the Livingston formation. It seems probable, however, that more than one period of folding affected the area, even after deposition of the Livingston formation and the Paleocene(?) strata in the present Crazy Mountains area. The almost perpendicular relationship of the trends of the faults and folds of the mountain flanks to the folds in the nearby syncline suggests two distinct intervals of folding.

The writer considers the following sequence of deformation probable, though not necessarily the only possible one.

(1) Early mountain uplift, Judith River time plus or minus, depending upon the age of the breccia (igneous or agglomerate) member of the Livingston formation, when the north flank of the Beartooth Mountains was the site of small volcanoes.

(2) Initiation of zones of weakness along the mountain edge and in the syncline, with perhaps attendant faulting and some folding, from Judith River(?) time on.

(3) Outlining of the north block of the Beartooth Mountains by the Deep Creek fault along the west and the Elbow Creek and Mill Creek faults to the south. The north edge was marked by a northward-steepening of beds and by the high-angle Lost Creek fault. Although these three steps are listed separately, they may have been closely related and may have been essentially contemporaneous.

(4) Compressive forces acting presumably southwestward caused folding and reverse faulting along the north flank of the mountains; preexisting structures were modified. This stage was later than the faulting that outlined the west flank of the mountains, because the Deep Creek fault along the west edge of the Beartooth Mountains was cut by the Suce Creek fault that originated during this period of deformation.

(5) Compression, possibly from the northwest, led to the formation of such structures as Hunters anticline and fault. A force couple, with eastward directed forces north of the area and westward directed forces south of the area, may have given the same results—a series of parallel anticlines such as Hunters, Elton, and Greeley.

The time of folding and faulting plays an as yet unknown part in the accumulation of oil and gas. Although no commercial quantities of oil or gas have been recovered within the Crazy Mountains syncline, such factors as the extensive igneous intrusions of Tertiary age, complexity of structures, and inadequate testing by drilling may be responsible for the lack of discoveries to date. The calcite veins (described on p. 432) almost certainly are fillings of tensional fractures that may have formed during the compression of stage 5 (described above). Whether they originated then or later is unknown, however the fractures might have been an avenue of escape for any trapped hydrocarbons. If the source of the calcite was the limestone bed of Paleozoic age, the tensional fractures were deep. Their crosscutting trends and the current hot spring activity at Hunters Hot Springs just northeast of the Elton quadrangle indicate a relatively late age for their formation.

ECONOMIC GEOLOGY

OIL AND GAS

Oil and gas have not been recovered in commercial quantities from the Crazy Mountains syncline west of the Dry Creek field (Tps. 6 and 7 S., R. 21 E.). Exploratory wells that were drilled deeper than 1,500 feet within the mapped area are described below and are shown on the structure contour map. The relationship of the time of origin of the geologic structures to the accumulation of oil and gas was discussed briefly above.

Operator and lessee	Location	Lowest formation reached	Total depth	Remarks
Richfield 1 Weiss	SW¼SE¼SW¼ sec. 20, T. 2 S., R. 11 E.	Morrison(?)	4,117	Abandoned.
Mid-American Oil Co. 1 Burgess-Preston.	NE¼NE¼SW¼ sec. 28, T. 2 S., R. 11 E.	Colorado shale	1,680	Drilling suspended.
Intermountain States Oil Co. 1 Burgess.	SE¼SW¼NW¼ sec. 28, T. 2 S., R. 11 E.	do	2,900	Abandoned.
R. C. Tarrant 1 Peterson.	N½SW¼NW¼ sec. 5, T. 2 S., R. 12 E.	Kootenai(?)	3,180	Abandoned, heavy flow of water.

Possibilities of finding oil and gas within the area depend in large part upon suitable structures and reservoir rocks. The mapped area is not so favorable in either respect as the Bighorn Basin. Most anticlines along the edge of the Crazy Mountains syncline are tightly folded and complicated by faults. The fault along the east flank of Hunters anticline may considerably influence the structural closure of that anticline at depth. On the other hand, the only structural closure on Mission Creek anticline was probably caused by faulting. A fault that crosses this anticline west of Mission Creek seems to have caused less than 500 feet of closure in the northwestward-plunging Mission Creek anticline west of the fault. Such anticlines as Elton and Greeley plunge so steeply that there is little likelihood of closure in the structure.

The Permian Phosphoria formation and the Pennsylvanian Tensleep sandstone, which are good reservoir rocks in the Bighorn Basin, may not yield oil within this area. The Permian rocks are absent in all outcrops, and the Quadrant quartzite, which is the stratigraphic equivalent of the Tensleep sandstone, has been largely cemented with quartz. Sandstones of Cretaceous age similar to producing sands in the Bighorn Basin have been tested by several wells, but shows of oil or gas have not been reported. Limestones of Devonian and Mississippian age may be suitable reservoirs in the area, but no well has reached them.

Igneous intrusions of Tertiary age in the Crazy Mountains syncline had an as yet unknown effect upon oil and gas accumulation in the area. Although the search for oil and gas in this area and other parts of the Crazy Mountains syncline has so far been unsuccessful, a sufficient number of wells have not been drilled to adequately test the region. Nevertheless, the area is less promising than other basins in eastern Montana and Wyoming.

COAL

Considerable coking coal was mined prior to 1908 near Cokedale, 7 miles west of Livingston, but the total tonnage produced was apparently unrecorded (Calvert, 1912, p. 37–38). The coal occurred in northward-dipping beds not many feet above the Virgelle sandstone. A thin bed of coal in what is considered to be about the same stratigraphic horizon in the W½ sec. 20, T. 2 S., R. 11 E. on the Joe Weiss ranch was mined for household use, but the small workings have caved in and no coal is visible in the outcrop.

CALCITE

Many veins of calcite, most of which are shown on the geologic map, occur within the Livingston formation. These veins strike northwest and are nearly vertical. Most range from 2 or 3 inches to 6 or 8 inches in thickness. The veins were mined east of the Elton quadrangle, the calcite reportedly used for its optical properties.

LIMESTONE AND DOLOMITE

In the formations of Cambrian age the Pilgrim limestone is the only one that is exposed in an accessible locality. The upper unit of the Pilgrim crops out in the canyon of the Yellowstone River 3 miles south of Livingston. It is readily identified in hand specimen by its oolitic structure. The weathered surface of the limestone in many localities is mottled, but the mottling is not notable in the Yellowstone River canyon. Hanson (1952) has described this and other limestone formations of Cambrian age. Near Shell Mountain where it was measured it is 175 feet thick; the upper 100 feet is massive ledge-forming largely oolitic limestone, and the lower 75 feet is mostly limestone breccia.

The Bighorn dolomite of Ordovician age consists of a basal massive member made up of light-gray and light-yellowish-gray dolomite that is 150 feet thick near Shell Mountain and an upper member consisting of about 50 feet of thin-bedded dolomite. The massive member crops out at the south end of the Yellowstone River canyon south of Livingston, but it is not readily distinguished by its topographic form.

Most beds in the Jefferson limestone of Devonian age are very argillaceous or silty. Limestone in the Madison limestone of Mississippian age is less argillaceous than the Devonian strata, and many beds are dolomitic. The basal 40 feet of cherty limestone in the Madison is very resistant to weathering and is a good marker zone in most localities. Part of the Madison is nearly pure calcium carbonate. Limestone from the upper part of the Madison was quarried and reduced in stone kilns in the canyon south of Livingston. Some of the kilns are still standing, even though they operated between 1900 and 1915 (Perry, 1949, p. 42). The average analyses of two samples from the quarried limestone is 97 percent calcium carbonate and 2.5 percent silica and alumina (Perry, 1949, p. 42). The Devonian and Mississippian strata dip steeply northward where they crop out in canyons along the edge of the mountains.

The Amsden formation of Mississippian and Pennsylvanian age contains some beds of limestone, but the limestone ranges considerably in thickness and lithology from one locality to another. Thin-bedded argillaceous limestones crop out along the southward-facing slopes near the top of Dry Creek ridge in secs. 26 and 35, T. 2 S., R. 10 E.

SHALE

Shale and claystone make up much of the Piper, Rierdon, and Morrison formations; shale in the Rierdon is calcareous. Dark-gray shale is interbedded with gray sandstones in the Colorado shale, and reddish-gray shale, which is possibly bentonitic, is abundant in the upper part of the Livingston formation. Most of the shale in the area is covered by soil; roadcuts and landslides along streams provide the best exposures.

GYPSUM

No gypsum was observed within the area. Thin beds may occur in the Piper formation, but there is little likelihood of finding gypsum in other formations. The redbeds in the Permian and Triassic rocks, which contain much gypsum in Wyoming, were removed by pre-Jurassic erosion and are absent north of Cinnabar Mountain 40 miles south of Livingston.

BENTONITE

No thick beds of bentonite, such as those that characterize the Upper Cretaceous strata farther east in Montana and Wyoming, were seen within the area. Thin beds are common in the lower part of the Colorado shale (see plate 36), but these are concealed by soil throughout most of their outcrop area. Thicker beds of bentonite may occur stratigraphically higher, but there is no evidence that they are present.

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PLATES 37–43

PLATE 37

[Figures natural size unless otherwise indicated]

FIGURES 1, 2. *Streptelasma trilobatum* Whiteaves (p. 474).
1. Calyx; 2, left alar side, USNM 124800. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

3, 5–7. "*Holophragma*" sp. (p. 474).
3. View of the cardinal side, ×2; 7, calyx, ×2, USNM 124801.
5. Alar side; 6, same view, ×2, USNM 124801. From Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

4, 8. *Streptelasma* cf. *S. latusculum* (Billings) (p. 474).
4. View of counter side; 8, calyx, USNM 124803. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

9. *Favosites* (*Paleofavosites*) cf. *F. prolificus* (Billings) (p. 474).
Fragment of corallum, USNM 124804. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

10, 11. *Sceptropora* cf. *S. facula* Ulrich (p. 474).
10, 11. Oblique and lateral views of one of the articulating segments, ×20, USNM 124805. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

12–15. *Hesperorthis* cf. *H. laurentina* (Billings) (p. 475).
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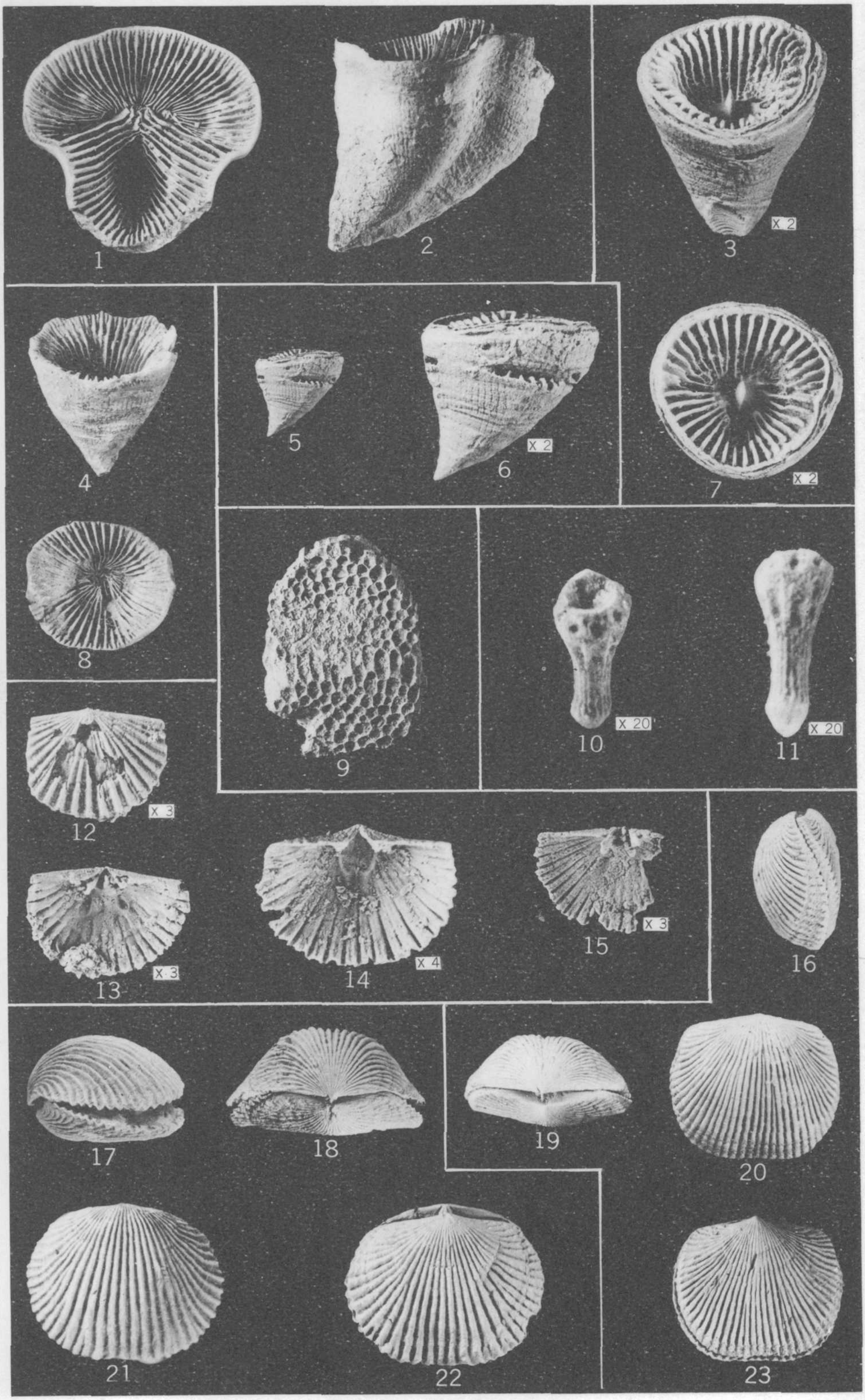
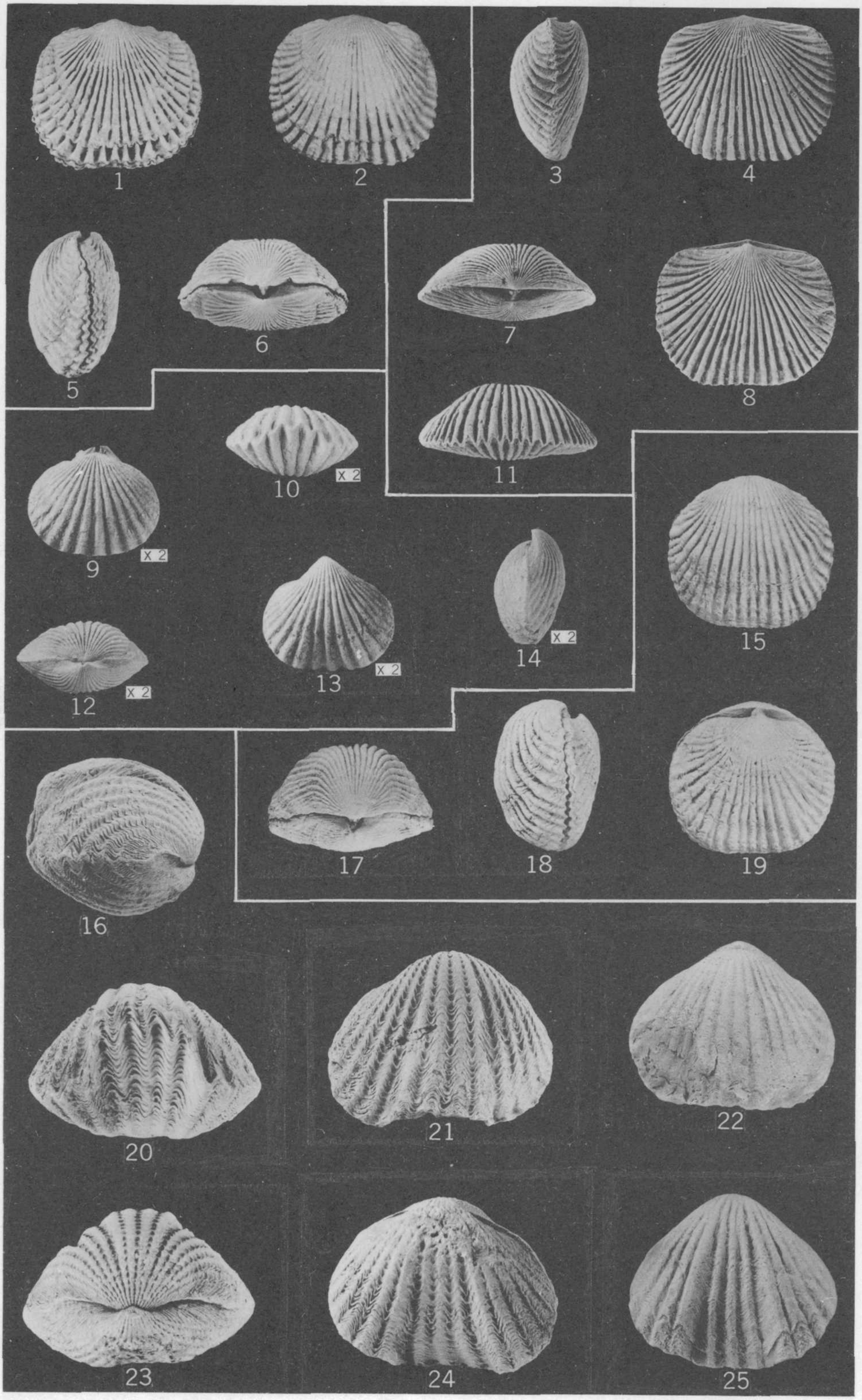
16. Lateral view; 19, posterior view; 20, 23, dorsal and ventral views, USNM 124808. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

17, 18, 21, 22. *Dinorthis* (*Pionorthis* (?)) cf. *D.* (*P.*) *occidentalis* Okulitch (p. 475).
17, 18. Lateral and posterior views; 21, 22, dorsal and ventral views, USNM 124809. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.



CORALS, BRYOZOAN, AND BRACHIOPODS (ORTHACEA), BIGHORN AND RED RIVER FORMATIONS



BRACHIOPODS (ORTHACEA AND RHYNCHONELLACEA), BIGHORN FORMATION

PLATE 38

[Figures natural size unless otherwise indicated]

FIGURES 1, 2, 5, 6. *Dinorthis* (*Pionorthis*(?)) *n. sp.* (*p.* 475).

1, 2. Ventral and dorsal views; 5, 6, lateral and posterior views, USNM 124810. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

3, 4, 7, 8, 11. *Dinorthis*(?) sp. (p. 475).

3, 7, 11. Lateral, posterior, and anterior views; 4, 8, Dorsal and ventral views, USNM 124811. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo. (The ventral valve of Okulitch's two cotypes for *Pionorthis occidentalis* may belong to this species.)

9, 10, 12–14. *Rhynchotrema iowense* Wang (p. 476).

9, 13. Dorsal and ventral views, × 2; 10, 12, 14, Anterior, posterior, and lateral views, × 2. USNM 124813. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

15, 17–19. *Dinorthis*(?) (*Pionorthis*(?)) n. sp. (p. 475).

15, 19. Dorsal and ventral views; 17, 18, posterior and lateral views, USNM 124812. Upper Ordovician, red shaly beds in the uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

16, 20–25. *Lepidocyclus gigas* Wang (p. 477).

16, 20, 23, Lateral, anterior, and posterior views; 21, 24, dorsal and ventral views (specimen slightly distorted), USNM 124814. 22, 25, dorsal and ventral views of undistorted specimen, USNM 124815, All from Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

PLATE 39

FIGURES 1–5. *Lepidocyclus perlamellosa* (Whitfield) (p. 477).

1, 2. Dorsal and ventral views, × 1; 3, 4, 5, posterior, lateral, and anterior views, × 1, USNM 124816. Upper Ordovician, red shaly beds of uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

6–8, 12, 13. *Hypsiptycha* cf. *H. anticostiensis* (Billings) (p. 478).

6, 7, 12. Posterior, anterior, and lateral views, × 2; 8, 13, ventral and dorsal views, × 2, USNM 124817. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

9–11, 14, 15. *Hypsiptycha* cf. *H. hybrida* Wang (p. 478).

9, 14. Dorsal and ventral views, × 2; 10, 11, 15, posterior, lateral, and anterior views, × 2, USNM 124818. Upper Ordovician, lower shale member, Stony Mountain formation, loc. D91f (CO), Shell Oil Co., Pine Unit No. 1 well, 8,986–9,010 ft.

16, 17. *Isotelus?* sp.

16, Cranidium, damaged, × 2, USNM 124821.

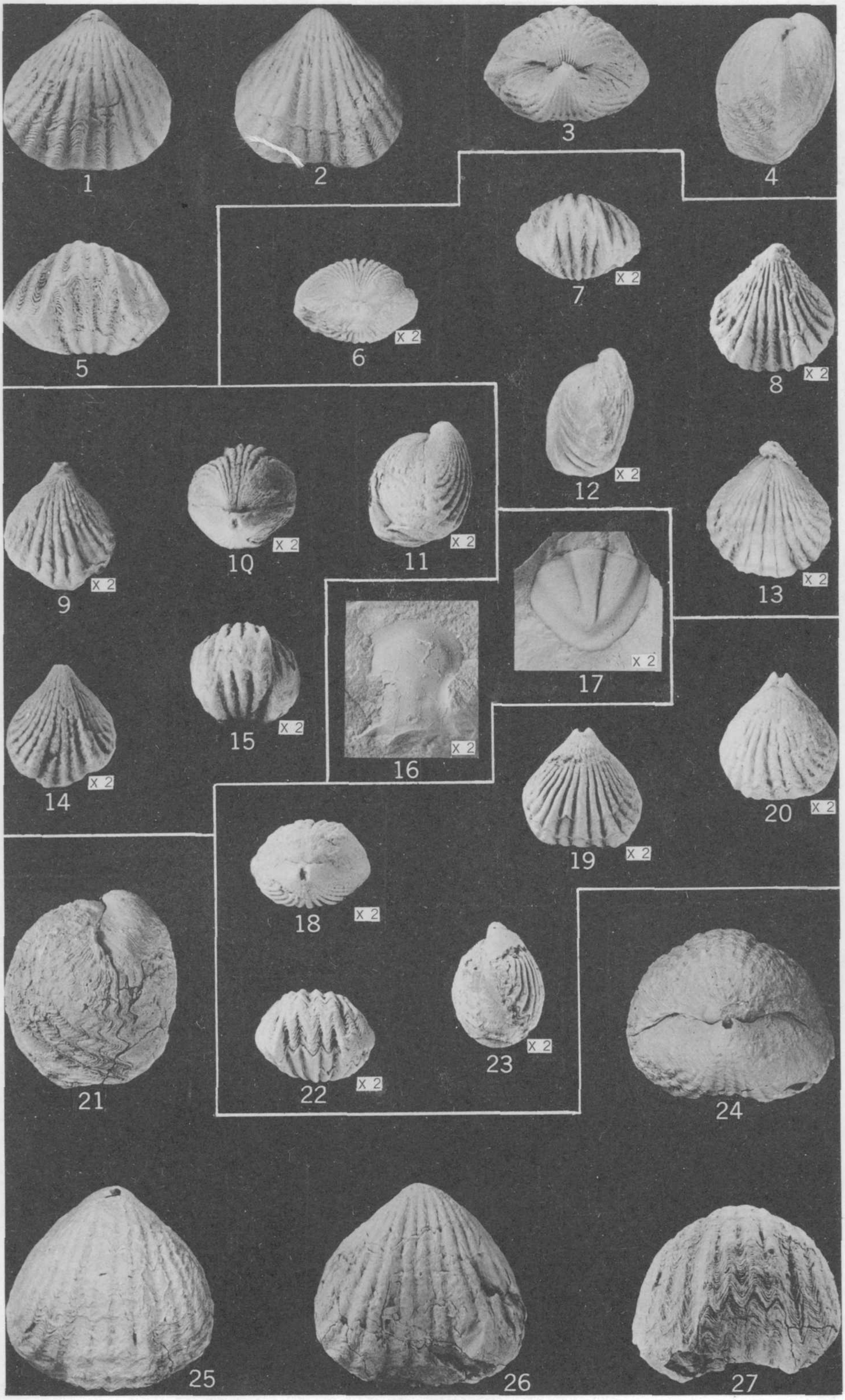
17. Pygidium × 2, USNM 124822. Upper Ordovician, lower shale member, Stony Mountain formation loc. D91f (CO), Shell Oil Co., Pine Unit No. 1 well, 8,986–9,010 ft.

18–20, 22, 23. *Hypsiptycha* cf. *H. hybrida* Wang (p. 478).

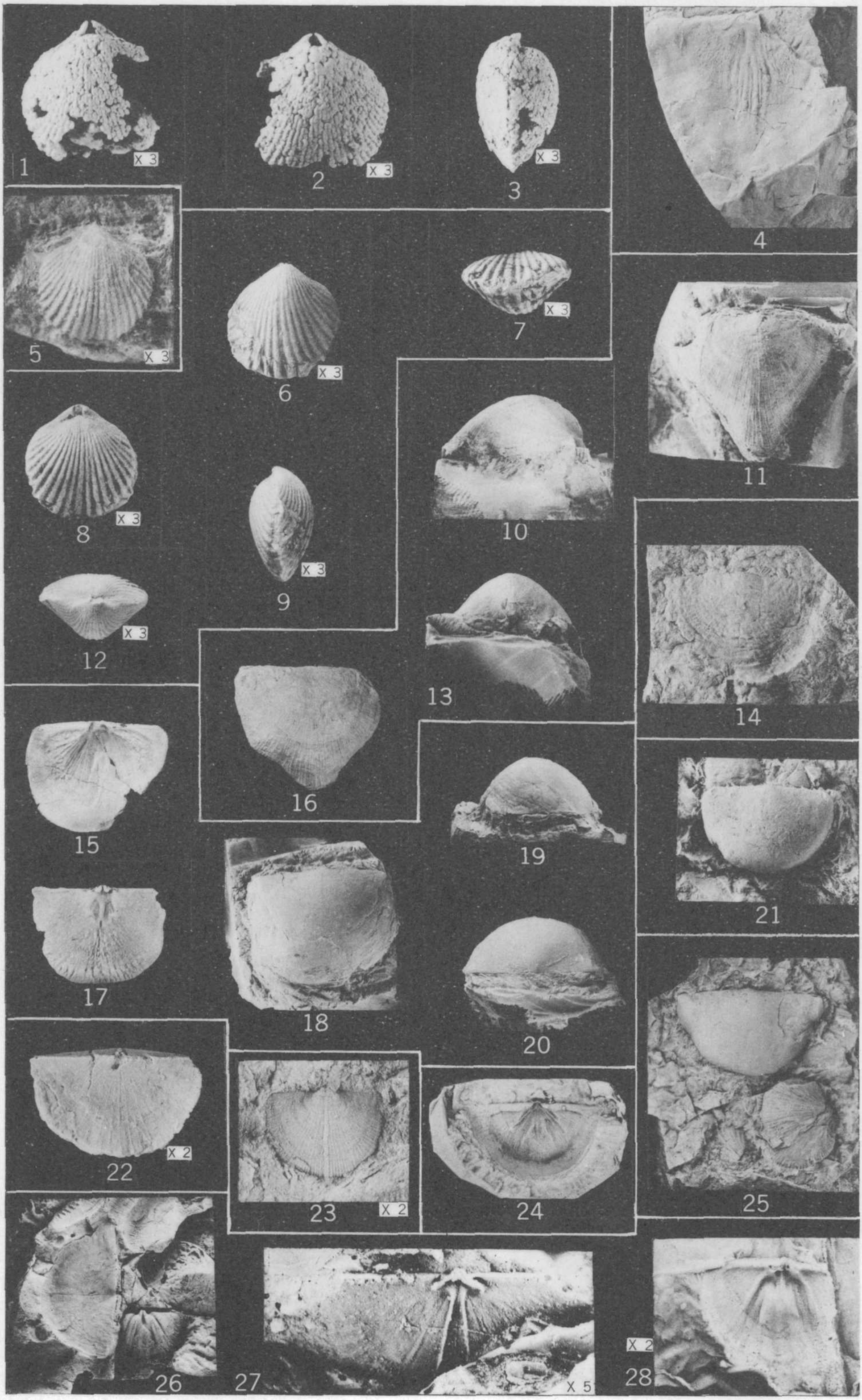
18, 22, 23. Posterior, anterior, and lateral views, × 2; 19, 20, ventral and dorsal views, × 2, USNM 124819. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

21, 24, 25–27. *Lepidocyclus capax* (Conrad) (p. 477).

21, 24, 27. Lateral, posterior, and anterior views, × 1; 25, 26, dorsal and ventral views, × 1, USNM 124820. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.



BRACHIOPODS (RHYNCHONELLACEA) AND TRILOBITE, BIGHORN AND STONY MOUNTAIN FORMATIONS



BRACHIOPODS (SPIRIFERACEA AND STROPHOMENACEA), STONY MOUNTAIN, RED RIVER, AND BIGHORN FORMATIONS

PLATE 40

[Figures natural size unless otherwise indicated]

FIGURES 1-3. *Catazyga* sp. (p. 479).

1, 2, 3. Dorsal, ventral and lateral views of a fragmentary silicified specimen, × 3, USNM 124823. Upper Ordovician, Red River formation, loc. D91d (CO), Shell Oil Co., Pine Unit No. 1 well, 9,103-9,116 ft.

4. *Strophomena* cf. *S. vetusta* James (p. 482).

Interior of dorsal valve, cut by coring bit, USNM 124824. Upper Ordovician, lower shale member, Stony Mountain formation, loc. D91f (CO), Shell Oil Co., Pine Unit No. 1 well, 8,986-9,010 ft.

5. *Zygospira* cf. *Z. resupinata* Wang (p. 479).

Ventral view of ventral valve, × 3, USNM 124825. Upper Ordovician, Red River formation, loc. D91e (CO), Shell Oil Co., Pine Unit No. 1 well, 9,023-9,043 ft.

6-9, 12. *Zygospira* cf. *Z. aequivalvis* Twenhofel (p. 479).

6, 8. Ventral and dorsal views, × 3.

7, 9, 12. Anterior, lateral, and posterior views, × 3, USNM 124826. Upper Ordovician, Red River formation, loc. D91c (CO), Shell Oil Co., Pine Unit No. 1 well, 9,122-9,128 ft.

10, 11, 13, 16. *Strophomena hecuba* Billings (p. 482).

10, 11, 13. Dorsal valve, dorsal, lateral, and posterior views, USNM 124827. Upper Ordovician, upper dolomitic member, Stony Mountain formation, loc. D90e (CO), Empire State Oil Co., Hathaway No. 1 well, 8,556-8,664 ft.

16. Dorsal view of a less nasute specimen, USNM 124828. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

14. *Strophomena* cf. *S. rugulifera* Wang (p. 483).

Ventral view, USNM 124829. Upper Ordovician, Red River formation, loc. D91e (CO), Shell Oil Co., Pine Unit No. 1 well, 9,023-9,043 ft.

15, 17, 19-21. *Megamyonia* cf. *M. ceres* (Billings) (p. 484).

15. Interior of a ventral valve, USNM 124830.

19. Interior of a dorsal valve, USNM 124831.

17, 20, 21. Lateral, ventral, and posterior views of a ventral valve, USNM 124832. All from Upper Ordovician, lower shale member, Stony Mountain formation, loc. D91f (CO), Shell Oil Co., Pine Unit No. 1 well, 8,986-9,010 ft.

18. *Megamyonia* sp. (cf. *M.* sp., Wang, 1949, p. 34, pl. 9C) (p. 485).

Ventral view of ventral valve, USNM 124833. Upper Ordovician, lower shale member, Stony Mountain formation, loc. D91f (CO), Shell Oil Co., Pine Unit No. 1 well, 8,986-9,010 ft.

22. *Thaerodonta* sp. (p. 480).

Dorsal view, × 2, USNM 124834. Upper Ordovician, red shaly beds of the uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

23-25. *Megamyonia* cf. *M. unicostata* (Meek and Worthen). (p. 483).

23. Ventral view of ventral valve, immature, tentatively referred this species, × 2, USNM 124835.

24. Interior of ventral valve, a rubber mold made from cast, USNM 124836. Upper Ordovician, Red River formation, loc. D92b (CO), Shell Oil Co., Little Beaver No. 1 well, 8,531-8,540 ft.

25. Ventral view of ventral valve, associated with *Diceromyonia* sp. USNM 124837. Upper Ordovician, lower shale member, Stony Mountain formation, loc. D91f (CO), Shell Oil Co., Pine Unit No. 1 well, 8,986-9,010 ft.

26-28. *Thaerodonta* cf. *T. recedens* (Sardeson) (p. 481).

26. Internal cast of ventral valve, associated with *Megamyonia* cf. *M. unicostata*, USNM 124838.

27. Interior of dorsal valve, a rubber mold, × 5, USNM 124839.

28. Interior of ventral valve, a rubber mold of cast shown in fig. 26, slightly distorted to show delthyrial cavities, × 2, USNM 124838. All from Upper Ordovician, Red River formation, loc. D92b (CO), Shell Oil Co., Little Beaver No. 1 well, 8,531-8,540 ft.

PLATE 41

[Figures natural size unless otherwise indicated]

FIGURES 1, 2. *Öpikina*? aff. *Ö. limbrata* Wang (p. 485).

1. Interior of large dorsal valve, USNM 124840.
2. Interior of small dorsal valve, USNM 124841.

Upper Ordovician, lower shale member, Stony Mountain formation, loc. D91f (CO), Shell Oil Co., Pine Unit No. 1 well, 8,986-9,010 ft.

3, 4, 7. *Megamyonia* aff. *N. nitens* (Billings) (p. 484).

Posterior, ventral, and lateral views, USNM 124842. Equals in part "*Leptaena nitens*" Billings as described by Twenhofel, 1928. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

5, 6, 9, 12, 16. *Diceromyonia storeya* Okulitch. (p. 487).

5, 12. Dorsal and ventral views, × 2;

6, 9, 16. Anterior, posterior, and lateral views, × 2, USNM 124843. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

8, 10, 11. *Holtedahlina* cf. *H. moniquensis* Foerste (p. 486).

8. Exterior of a dorsal valve, × 2, USNM 124844.
10. Interior of dorsal valve, × 2, USNM 124845.
11. Interior of dorsal valve, × 2, USNM 124846.

All specimens poorly silicified and fragmentary. All from Upper Ordovician, Red River formation, loc. D91d (CO), Shell Oil Co., Pine Unit No. 1 well, 9,103-9,116 ft.

13-15, 17-21. *Diceromyonia* cf. *D. ignota* (Sardeson) (p. 487).

13. Interior of ventral valve, × 2, USNM 124847.

14, 15, 21. Anterior, posterior, and lateral views, × 2.

18, 20. Ventral and dorsal views, × 2, USNM 124848. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.

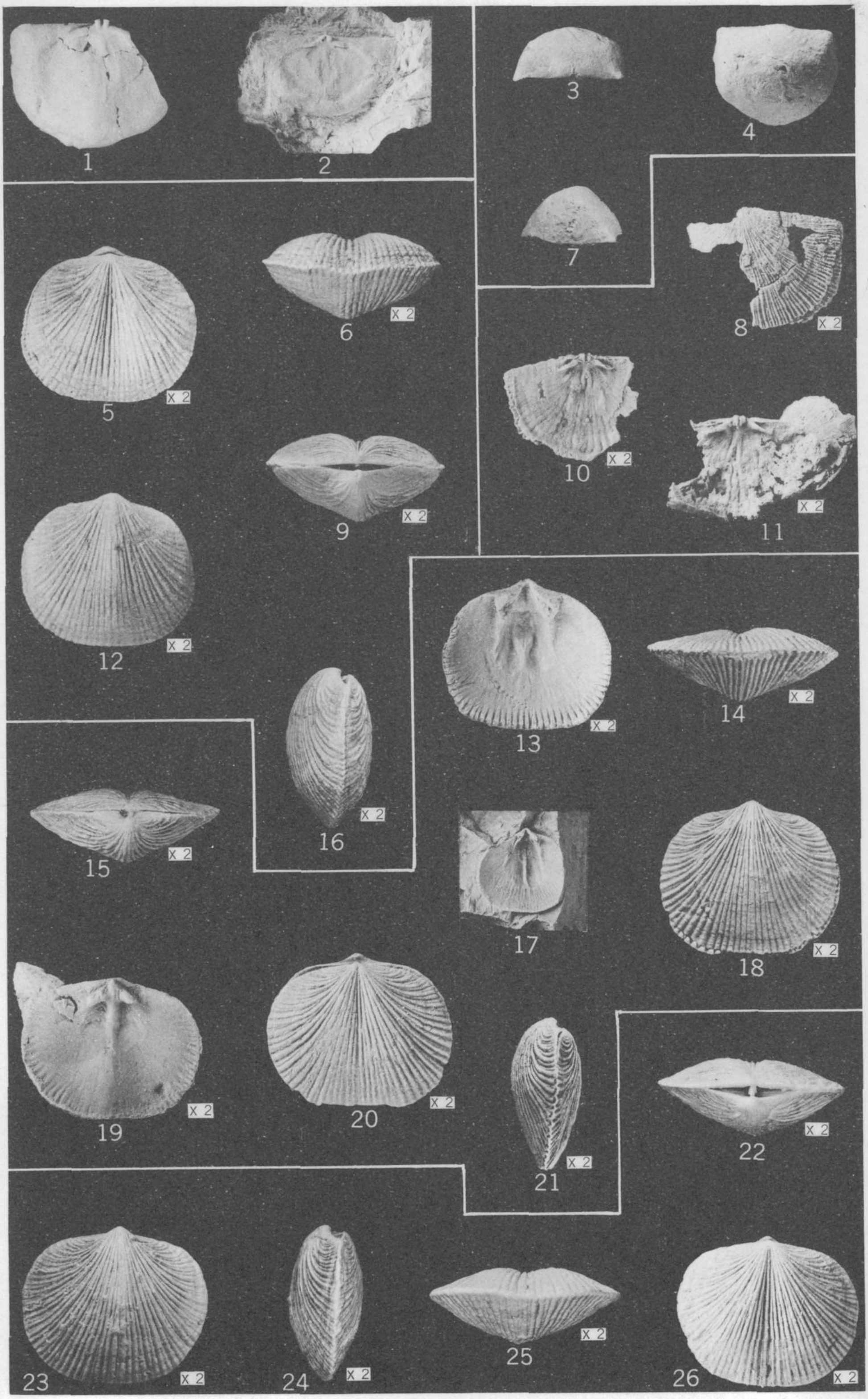
17. Interior of ventral valve showing narrow ridge between diductor scars, USNM 124849.

19. Interior of dorsal valve, × 2, USNM 124850. Upper Ordovician, lower shale member, Stony Mountain formation, loc. D91f (CO), Shell Oil Co., Pine Unit No. 1 well, 8,986-9,010 ft.

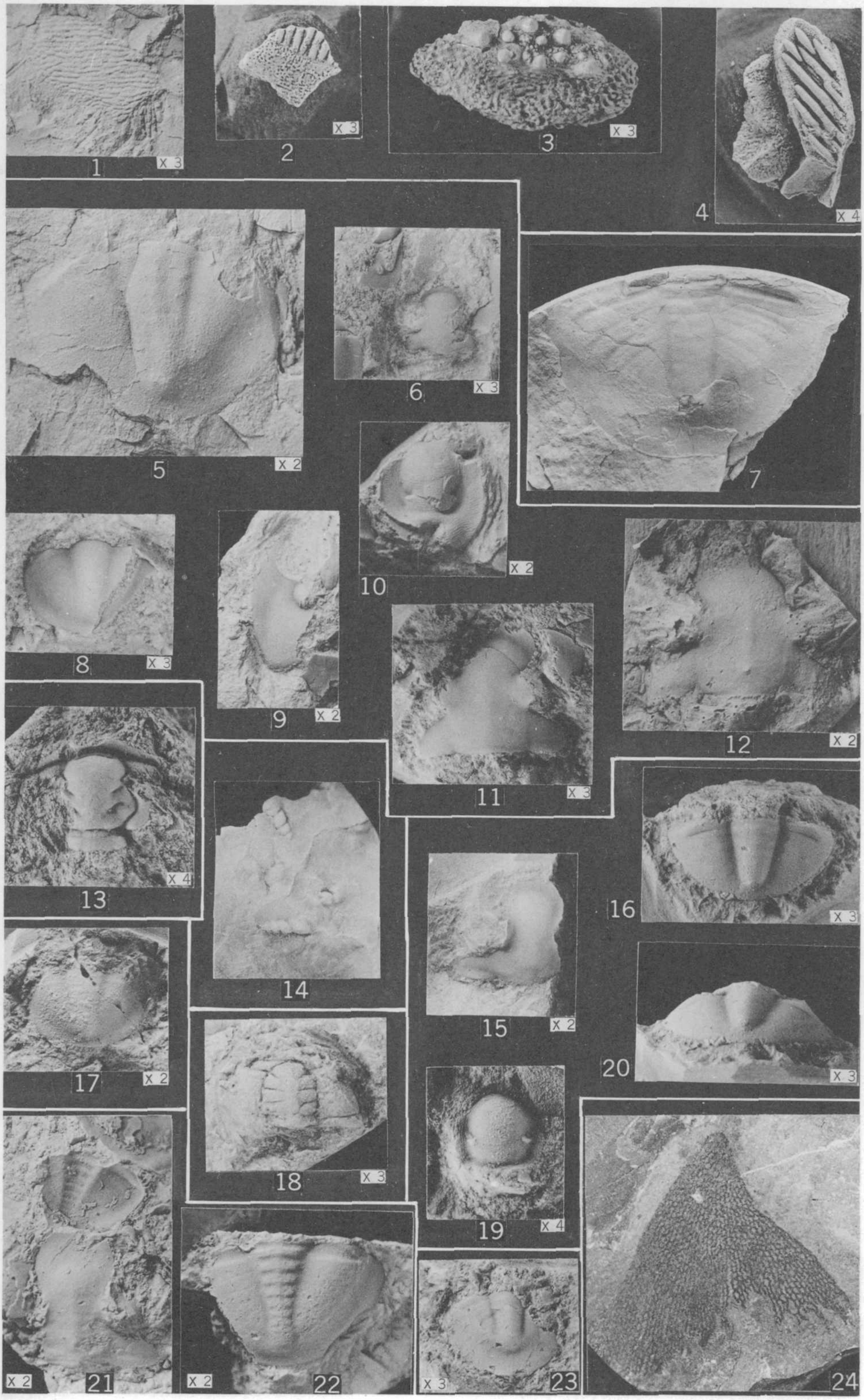
22-26. *Diceromyonia* n. sp. (aff. *D. tersa*) (p. 487).

22, 24, 25. Posterior, lateral, and anterior views, × 2.

23, 26. Ventral and dorsal views, × 2, USNM 124851. Upper Ordovician, red shaly beds in uppermost part of Bighorn dolomite, loc. D1 (CO), South Fork of Rock Creek, Johnson County, Wyo.



BRACHIOPODS (STROPHOMENACEA AND PUNCTATE FORMS), STONY MOUNTAIN, RED RIVER, AND BIGHORN FORMATIONS



TRILOBITES, GRAPTOLITE, AND FISH, WINNIPEG AND DEADWOOD FORMATIONS

PLATE 42

FIGURES 1–4. Fragmentary fish plates.

1, 2, 4. *Eriptychius americanus* Walcott, × 3, × 3, × 4, USNM 20868, 20869, 20870.

3. *Astraspis desiderata* Walcott, × 3, USNM 20871. Winnipeg formation, loc. D69 (CO), Shell Oil Co., Pine Unit No. 1 well, 9,525–9,531 ft.

5, 6, 8–12. *Kirkella* aff. *K. fillmorensis* Hintze (p. 493).

5. Pygidium, × 2, USNM 124852.

6. Ventral view of fragmentary posterior portion of free cheek and dorsal view of immature cranidium, × 3, USNM 124853.

8. Immature pygidium, × 3, USNM 124854.

9. Left free cheek, immature, × 2, USNM 124855.

10. Hypostome, broken, but showing characteristic "wings," × 2, USNM 124857.

11. Cranidium, immature, damaged, × 3, USNM 124856.

12. Cranidium, damaged, rubber cast of original, × 2, USNM 124858. All from Lower Ordovician, Deadwood formation, loc. D66e (CO), Shell Oil Co., Pine Unit No. 1 well, 9,660–9,666 ft.

7. *Ogyginus*? sp. (p. 494).

Pygidium, × 1, USNM 124859. Lower Ordovician, Deadwood formation. loc, D66e (CO), Shell Oil Co., Pine Unit No. 1 well, 9,660–9,666 ft.

13. *Apatokephalus* cf. *A. canadensis* Kobayashi (p. 499).

Cranidium, × 4, USNM 124860. Lower Ordovician, Deadwood formation, loc. D66e (CO), Shell Oil Co., Pine Unit No. 1 well, 9,660–9,666 ft.

14. *Hormotoma*? sp.

Two small specimens, × 1, USNM 124861. Lower Ordovician, Deadwood formation, loc. D66e (CO), Shell Oil Co., Pine Unit No. 1 well, 9,660–9,666 ft.

15, 16, 19, 20. *Megalaspidella* cf. *M. orthometopa* Harrington (p. 492).

15. Cranidium, lacking palpebral lobes, × 2, USNM 124862.

16, 20. Pygidium, dorsal and posterior views, × 3, USNM 124863.

19. Fragmentary hypostome, rubber cast, × 4, USNM 124864. Lower Ordovician, Deadwood formation, loc. D66d–e (CO), Shell Oil Co., Pine Unit No. 1 well, 9,660–9,690 ft.

17. *Kirkella*? sp. (p. 492).

Pygidium, × 2, USNM 124865. Probably same as those figured above. Lower Ordovician, Deadwood formation, loc .D66d (CO), Shell Oil Co., Pine Unit No. 1 well, 9,672–9,678 ft.

18. *Protopliomerops* cf. *P. superciliosa* Ross (p. 503).

Cranidium, × 3, USNM 124866. Lower Ordovician, Deadwood formation, loc. D66d (CO), Shell Oil Co., Pine Unit No. 1 well, 9,672–9,678 ft.

21, 22. *Asaphellus*? sp. (p. 494).

21. Cranidium and ventral surface of pygidium, × 2, USNM 124868.

22. Pygidium, × 2, USNM 124867. Lower Ordovician, Deadwood formation, loc. D66b (CO), Shell Oil Co., Pine Unit No. 1 well, 9,698 ft.

23. Unidentified pygidium (p. 503).

× 3, USNM 124869. This should be compared with Hintze, 1952, pl. IX, fig. 19. Lower Ordovician, Deadwood formation, loc. D66d (CO), Shell Oil Co., Pine Unit No. 1 well, 9,678–9,684 ft.

24. *Dictyonema* sp.

× 1, USNM 124870. Lower Ordovician, Deadwood formation, loc. D70 (CO), Shell Oil Co., Richey area, Northern Pacific R. R. No. 1 well, 10,484 ft.

PLATE 43

FIGURES 1–4, 6, 7. *Kayseraspis* aff. *K. asaphelloides* Harrington (p. 497).

1. Fragmentary cranidium and immature pygidium with terminal spine, × 2, USNM 124871.
2. Cranidium lacking palpebral lobes, USNM 124872.
3. Pygidium immature but with mature proportions, × 2, USNM 124873.
4. Mature pygidium cut by coring bit; terminal spine incomplete, × 2, USNM 124874.
6, 7. Immature pygidia, showing slight change in shape and in definition of segmentation, × 4, USNM 124875, 124876. All from Lower Ordovician, Deadwood formation, loc. D66b (CO), Shell Oil Co., Pine Unit No. 1 well, 9,701–9,708 ft.

5, 12, 13. *Megalaspis planilimbata* var. *cyclopyge* Harrington (p. 490).

5. Pygidium × 2, USNM 124877.
12. Cranidium with pathologic(?) development of one muscle scar and obverse of pygidium shown in fig. 13, × 2, USNM 124878.
13. Small pygidium, × 2, USNM 124879, Lower Ordovician, Deadwood formation, loc. D66b (CO), Shell Oil Co., Pine Unit No. 1 well, 9,701–9,705 ft.

8. *Nanorthis*? sp.

× 2, USNM 124880. Dorsal valve, dorsal view. Lower Ordovician, Deadwood formation, loc. D66b (CO), Shell Oil Co., Pine Unit No. 1 well, 9,703–9,710 ft.

9, 10. Unidentified hypostomes (p. 490, 494, 497).

9. Associated with *Asaphellus*? sp. and *Megalaspis planilimbata* var. *cyclopyge* × 2, USNM 124881.
10. Associated with *Kayseraspis* aff. *K. asaphelloides*, × 2, USNM 124882. Lower Ordovician, Deadwood formation, loc. D66b (CO), Shell Oil Co., Pine Unit No. 1 well, 9,701–9,709 ft.

11, 17. *Lloydia* cf. *L. saffordi* (Billings) (p. 489).

11. Small pygidium, × 2, USNM 124883.
17. Pygidium, × 2, USNM 124884. Lower Ordovician, Deadwood formation, loc. D66b (CO), Shell Oil Co., Pine Unit No. 1 well, 9,709 ft. (Species also present, D66c (CO), 9,690–9,696 ft.)

14. Syntrophiid brachiopod, not identified generically.

Dorsal valve, × 2, USNM 124885. Lower Ordovician, Deadwood formation, loc. D66a (CO), Shell Oil Co., Pine Unit No. 1 well, 9,711 ft.

15. Unidentified pygidium (p. 503).

× 2, USNM 124886. Compare with Ross, 1951, pl. 19, figs. 30, 31. Lower Ordovician. Deadwood formation, loc. D66a (CO), Shell Oil Co., Pine Unit No. 1 well, 9,715 ft.

16. *Didymograptus*? sp. or *Tetragraptus*? sp.

Immature, × 4, USNM 124887. Lower Ordovician, Deadwood formation (associated with *Bryograptus*? sp.), loc. D66a (CO), Shell Oil Co., Pine Unit No. 1 well, 9,715 ft.

18–20. *Leiostegium manitouensis* Walcott (p. 489).

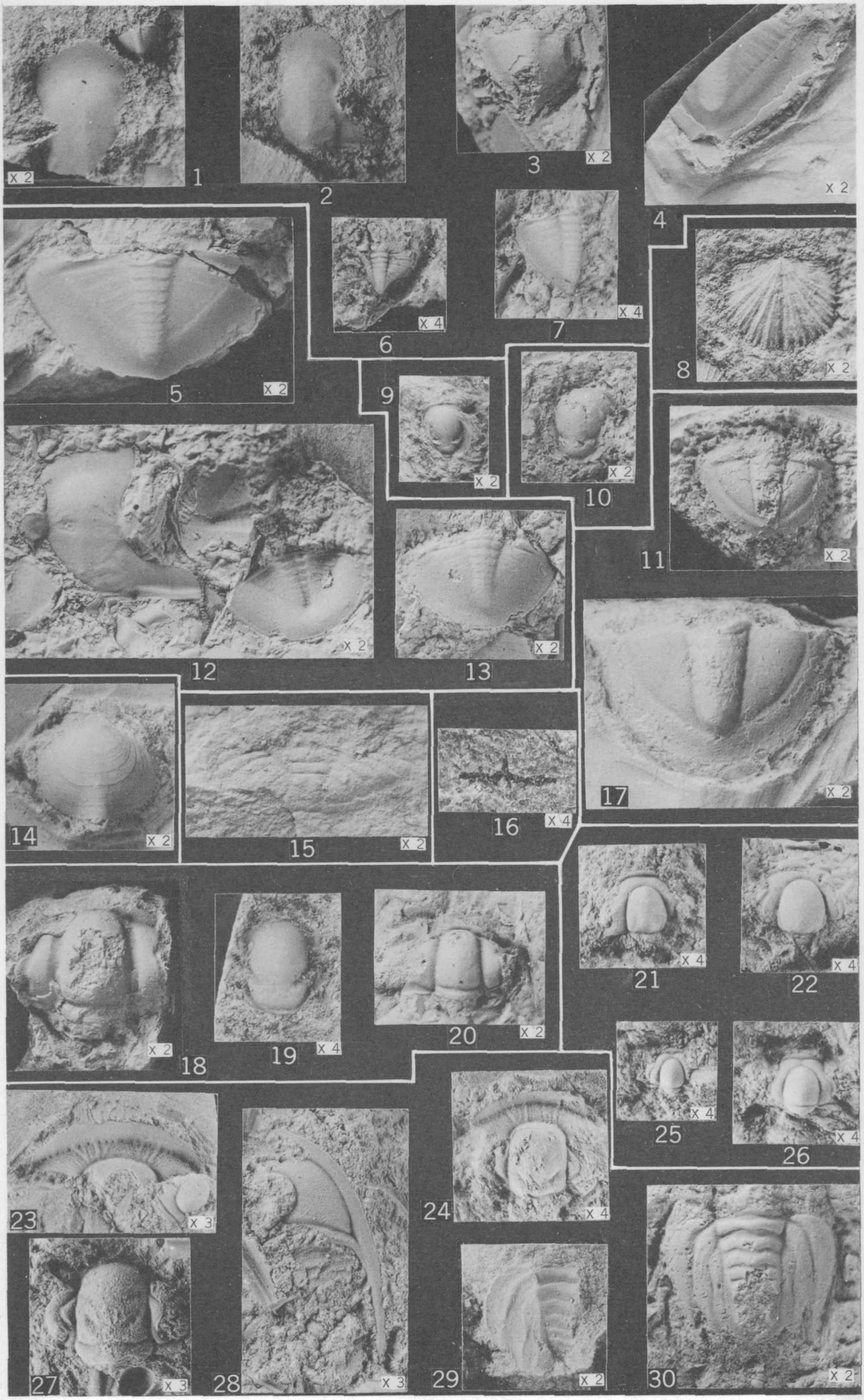
18. Cranidium, decorticated, × 2, USNM 124888.
19. Hypostome, × 4, USNM 124889.
20. Cranidium, × 2, USNM 124890. All from Lower Ordovician, Deadwood formation, loc. D70a (CO), Shell Oil Co., Richey area, Northern Pacific R. R. No. 1 well, 10,500–10,509 ft.

21, 22, 25, 26. *Hystricurus* sp. (p. 488).

Four cranidia, × 4, USNM 124891, 124892, 124893, 124894, showing change in median preglabellar furrow with growth. 25, 26, may belong to separate species (cf. *H. robustus* Ross). All from Lower Ordovician, Deadwood formation, loc. D70a (CO), Shell Oil Co., Richey area, Northern Pacific R. R. No. 1 well, 10,500–10,509 ft.

23, 24, 27–30. *Kainella* sp. (p. 500).

23. Front of glabella, preglabellar field, and rim, × 3, USNM 124895.
24. Cranidium immature, × 4, USNM 124896.
27. Cranidium, lacking preglabellar field, × 3, USNM 124897.
28. Free cheek, showing granulose ornamentation of ocular platform, × 3, USNM 124898.
29. Obverse of pygidium shown in fig. 30, fragmentary, × 2, USNM 124899.
30. Pygidium, lacking rear of axis, × 2, USNM 124900. All from Lower Ordovician, Deadwood formation, loc. D70a (C), Shell Oil Co., Richey area, Northern Pacific R. R. No. 1 well, 10,500–10,509 ft.



BRACHIOPODS, TRILOBITES, AND GRAPTOLITE, DEADWOOD FORMATION