GEOLOGY OF THE LIMESTONE HILLS, BROADWATER COUNTY, MONTANA

by

Edward T. Ruppel

August 1950

OPEN FILE

50-14

CONTENTS

ILLUSTRATIONS

GEOLOGY OF THE LIMESTONE HILLS,

BROADWATER COUNTY, MONTANA.

Edward T. Ruppel

ABSTRACT

The Limestone Hills, a natural topographic unit having an area of about 16 square miles, are situated a few miles west and southwest of Townsend, Broadwater County, Montana.

They are composed of pre-Cambrian, Paleozoic, and Mesozoic sedimentary rocks into which igneous rocks of several types and forms were intruded during late Cretaceous or early Tertiary time. Later in the Tertiary, beds of volcanic ash were deposited on the truncated edges of the older strata.

The apparent conformity of all the Paleozoic and Mesozoic sedimentary rocks indicates that no severe structural deformation occurred in the Limestone Hills prior to the late Cretaceous or early Tertiary, at which time the area was folded to form the steeply dipping western limb of a broad, north-trending anticline. Numerous high angle normal faults transverse to the trend of the strata, and two high angle normal faults parallel to the trend of the strata are present in the area, but it was not possible to determine definitely whether they are contemporary with or later than the folding. Similarly, the relationships of the three general types of igneous rock--granodiorite and related dioritic rocks, microgabbro, and quartz latite--to the structural deformation and to each other could not be determined in the Limestone Hills.

Each type of igneous rock occurs in a characteristic form--the granodiorite and related dioritic rocks in sills and, more rarely, dikes, and the microgabbro and quartz latite in stocks.

Mineral resources extracted from the Limestone Hills to date are building stone from the upper part of the Meagher limestone, and quartz sandstone from the Flathead quartzite. Copper minerals have been found in three localities, but not in commercial quantities.

INTRODUCTION

Location of Area

The Limestone Hills are in west-central Montana a few miles west and southwest of Townsend, the seat of Broadwater County. They lie in the eastern half of the Radersburg Quadrangle (lat. 46°-46°30' N., long. 111°30'-112° W.). The hills are a distinctive topographic unit, bordered by lower terrain to the south, east, and west, and somewhat arbitrarily delimited by the valley of Indian Creek on the north. The area mapped is bounded on the east and west by two roads leading from Townsend to Radersburg, on the south by the gravel-covered flood plain of Crow Creek, and on the north by Indian Creek.

Townsend, the principal community of the Townsend Valley, is approximately midway between Helena and Three Forks. It is on U. S. Highway 10 N. and on the Northern Pacific Railway.

Topography

The most prominent topographic feature in the Limestone Hills is the high sharp ridge (pl. 2A) that trends about north through the full length of the eastern part of the hills. This ridge, composed of Cambrian dolomite and limestone, attains a maximum height of about 650 feet and an average height of about 400 feet above the adjacent dry valleys. In the northeastern part of the area, an equally prominent hogback, capped by basal Cambrian quartzite, lies to the east of the dolomite ridge. The west-central part of the area is characterized by strike ridges of Carboniferous limestones and quartzite (pl. 2B). These ridges range in height from 200 to 550 feet above the surrounding valleys. Lower Cretaceous limestone, intruded by a granodiorite sill, forms a low-strike ridge close to the western boundary of the area.

Shale, mudstone, and siltstone formations and igneous rocks typically are eroded to norh- or south-trending valleys or swales between the more resistant carbonate and sandstone rock units. The most prominent of these is the broad flat valley developed in a thick granodiorite sill in the central part of the region.

In summary, the limestone, dolomite, and sandstone formations in the Limestone Hills stand in relief as north-trending ridges. The formations composed of finer clastic sedimentary rocks and igneous rocks commonly have been carved into valleys and swales between the more resistant units.

Plate 2

A. View northwestward into southern Limestone Hills; ridge of Cambrian dolomite in center and right background; ridge of Carboniferous limestone at left.

B. View north into southern Limestone Hills; ridges of Carboniferous limestone and quartzite in center; Cambrian dolomite caps ridge at right.

Field Work

The field work was done during July, August, and September of 1949. The geology was mapped on aerial photographs at a scale of 1:24,000, and was transferred to a topographic base map by means of a vertical sketchmaster. The topography for this base was mapped for the U. S. Bureau of Reclamation by Fairchild Aerial Surveys, using photogrammetric methods. All stratigraphic sections were measured by use of a Brunton compass and 100-foot tape. Color terms used in the description of rocks are those standardized on the Rock-color Chart distributed by the National Research Council.

Previous Geologic Investigations

The region including the Limestone Hills was first studied geologically in 1860, when the Raynolds Expedition, with F. V. Hayden as geologist, explored the Yellowstone and Missouri Rivers. The geologic map which accompanies Hayden's report (1869) 1/ shows the area as being composed entirely of Carboniferous limestone and, in his discussion of the area, Hayden (p. 90) states that these limestones swing northward along the Missouri River from a point 20 to 25 miles west of Three Forks.

In the 65 years following Hayden's reconnaissance mapping, no geologic studies were made in the Limestone Hills, although fairly intensive work was done on the mineral deposits of the adjacent Radersburg district, on the stratigraphy and structural geology of the Three Forks-Lombard region about 20 to 30 miles to the south, and on the geology and mineral deposits of the Helena mining district and districts adjacent to it about 50 to 60 miles to the north.

In a report on the geology and ground water resources of the Townsend Valley, J. T. Pardee (1926, pp. 13-15) included a geologic map showing the entire valley, and briefly mentioned the general location and stratigraphy of the Limestone Hills. D. D. Condit (Condit, et. al., 1928, p. 177), in a reconnaissance study of phosphate rock in western Montana, noted the excellent exposures of sandstone and limestone along the eastern margin of the Limestone Hills.

The most recent geologic work in the Townsend-Radersburg area was done by A. V. Corry (1933, pp. 1-23), who briefly described the stratigraphy of the area and made a small-scale reconnaissance map. The major part of Corry's paper deals, however, with the mineral deposits of the nearby Radersburg and Hassel mining districts.

1/ All references appear in bibliography at end of this report.

Acknowledgments

The Writer is indebted to Mr. M. R. Klepper of the U. S. Geological Survey for his frequent assistance and many helpful suggestions and to Dr. S. H. Knight, Chairman of the Department of Geology at the University of Wyoming, for making available the equipment and facilities of the Department.

Thanks are extended to Mr. Russell S. Stewart of Townsend, Montana, and to the Vermont Marble Company, Proctor, Vermont, for furnishing information regarding quarrying activities in the Limestone Hills and for permission to incorporate that information in this manuscript.

STRATIGRAPHY

The sedimentary rocks in the Limestone Hills have a aggregate thickness in excess of 6,000 feet, and include str pre-Cambrian, Paleozoic, Mesozoic, and Cenozoic age as s the following generalized tabulation. No rocks of Ordovician, Silurian, or Triassic age are present.

Generalized Stratigraphic Section in
the Limestone Hills Area, Broadwater County, Montana

Age	Group and formation	Thic (fe
Quaternary	Alluvium (Flood plain)	--
Tertiary	Volcanic ash and underlying conglomerate	---
	UNCONFORMITY	
Cretaceous		
Upper Cretaceous	Sedimentary rocks, undivided	---
Lower Cretaceous	Kootenai formation	530
Jurassic		
Upper Jurassic	Morrison formation	525
	Swift sandstone	20
	UNCONFORMITY	
Permian	Phosphoria formation	45
Carboniferous		
Pennsylvanian	Quadrant formation	325
Mississippian and Pennsylvanian	Amsden formation	260
Mississippian	Madison group	
	Mission Canyon Limestone	1,105
	Lodgepole limestone	595
Devonian		
Upper Devonian	Three Forks shale	360
	Jefferson dolomite	475
Devonian (?)	Dry Creek (?) shale (upper unit -)	
	PROBABLE UNCONFORMITY	110
Cambrian		
Upper Cambrian (?)	Dry Creek (?) shale (lower unit -)	
Upper Cambrian	Pilgrim limestone	420
Middle Cambrian	Park shale	205
	Meagher limestone	510
	Wolsey shale	390
	Flathead quartzite	100
	UNCONFORMITY	
Pre-Cambrian	Belt series (not divided into formations in this study)	---

Pre-Cambrian Rocks

The oldest rocks in the area belong to the Belt series of pre-Cambrian age and probably are a part of the Spokane formation (Walcott, 1899, p. 207). These rocks are mainly moderate red to grayish red and pale olive to grayish-yellow green, siliceous and micaceous, fissile to blocky siltstone and shale. Interbeds of reddish quartzite, spaced at varying intervals, are fairly common. In the area mapped, the thickness of the unit is at least 800 feet.

Cambrian System

The earliest work on the Cambrian rocks of Montana was done by A. C. Peale (1893, pp. 20-25) in the Three Forks region. He divided the Cambrian strata into two formations, (1) the Flathead formation, consisting of (ascending) the Flathead quartzite and the Flathead shale, and (2) the Gallatin formation, consisting of (ascending) the Tribolite limestones, Obolella shales, Mottled limestones, Dry Creek shales, and Pebbly limestones. This division was later modified by Weed (1900, pp. 284-287) and Blackwelder (1918, p. 417) to give the present classification of Cambrian rocks in south-central Montana. The present generally accepted classification of Cambrian rocks in central and southwestern Montana was first proposed by Weed (1900, pp. 285-287) for the Cambrian section in the Little Belt Mountains. In this region, Weed divided the Cambrian rocks into seven formations, the Flathead quartzite, Wolsey shale, Meagher limestone, Park shale, Pilgrim limestone, Dry Creek shale, and Yogo limestone, in ascending order. This classification was later emended by Deiss (1936, pp. 1317-1342), who redefined the lower six formations and eliminated the seventh, the Yogo limestone, which may be equivalent to strata now included in the Devonian (Sloss and Laird, 1947, p. 1415). Deiss' emended classification, based on exposures of Cambrian rocks in the central Montana-Yellowstone Park region, is followed in this paper.

Cambrian rocks in the Limestone Hills have a total thickness of about 1,730 feet and consist of a basal quartzite formation overlain by alternating shale and carbonate rock units. The sandstone and carbonate rock units are typically well exposed in the map area. The three shaly units commonly form depressions and are exposed only partially in stream cuts.

Flathead quartzite

The Flathead quartzite is the basal unit of the Cambrian section in the Limestone Hills. It is of Middle Cambrian age (Deiss, 1936, p. 1341), and overlies the pre-Cambrian rocks with no apparent angular discordance. The formation ranges in thickness from a maximum of 276 feet to a minimum of 93 feet in the central Montana-Yellowstone Park region (Deiss, 1936, p. 1328).

In the Limestone Hills, the Flathead quartzite is about 100 feet thick at locality 1 (pl. 1), in the northern part of the area and about 120 feet thick at the Stewart quarry (pl. 3) in the northwest corner of sec. 27, T. 6 N., R. 1 E., about 4.5 miles south of locality 1. The formation typically consists of grayish red, grayish pink, and grayish orange pink fine- to medium-grained dense homogeneous quartzitic sandstone. At locality 1 (pl. 1) a pebble conglomerate layer 6 inches thick is present at the base of the formation.

The Flathead quartzite forms a low ridge extending in a north-south direction along the eastern edge of the Limestone Hills.

Detailed stratigraphic section of the Flathead quartzite, measured at section locality 1 (pl. 1) SE$\frac{1}{4}$ sec. 34, T. 7 N., R. 1 E.

	Feet
Wolsey shale:	
15. Siltstone, medium to dark gray, very micaceous, irregularly laminated; laminae range from 0.03 to 0.01 inch in thickness and from medium gray to dark greenish gray; weathers medium dark gray; mildly to moderately metamorphosed.	7.7
Flathead quartzite:	
14. Sandstone, grayish orange-pink, grayish pink, and pale red, quartzitic, vitreous, dense, homogeneous, medium-grained; weathers reddish brown, dark yellowish orange, and moderate dark yellowish brown.	3.4
13. Sandstone, varicolored: light to medium gray, pale red, and grayish yellow-green, fine-grained, thin- and irregular-bedded.	0.8
12. Sandstone; similar to unit 14.	4.8
11. Sandstone, grayish orange-pink, grayish pink, and pale red, silty, thin- and irregular-bedded.	0.4
10. Sandstone; similar to unit 14.	0.3
9. Siltstone, medium light gray to medium gray, very coarse grained, thin-bedded; irregular wavy laminae average about 0.05 inch in thickness.	0.4
8. Sandstone, pinkish gray, quartzitic, dense, homogeneous, medium-grained; weathers reddish brown, dark yellowish orange, and moderate dark yellowish brown.	13.5
7. Sandstone, grayish orange-pink, pinkish gray, and pale red, quartzitic, dense, homogeneous, medium-grained; conspicuous bedding cracks spaced from 0.3 foot to 2 feet apart, with alternating zones of slightly different color and grain size ranging from less than 1 inch to about 3 inches in thickness; in part cross-bedded on a small scale; weathers reddish brown, very dusky red, and dusky brown.	23.3

		Feet
6.	Shale, medium gray, carbonaceous (?), highly micaceous, fissile.	0.3
5.	Sandstone; similar to unit 7.	11.8
4.	Sandstone; similar to unit 8.	8.4
3.	Sandstone; similar to unit 7.	31.6
2.	Conglomerate, grayish pink, grayish orange-pink, and almost white sandstone matrix with pale red, grayish pink, and almost white, vitreous, rounded quartzite pebbles that range from 0.05 to 0.25 inch in maximum dimension.	0.5
	Total thickness of Flathead quartzite	99.5

Unconformity

Belt series:

1. Shale, grayish red, very fissile. Not measured.

Plate 3

View of Stewart quarry in well-bedded Flathead quartzite.

Wolsey shale

The Wolsey shale, which is of Middle Cambrian age (Deiss, 1936, p. 1341), overlies the Flathead quartzite. Its contact with the Flathead in the Limestone Hills is commonly gradational over a thickness of about 40 feet. The formation has a maximum thickness of 363 feet and a minimum thickness of 150 feet in the central Montana-Yellowstone Park region (Deiss, 1936, p. 1329).

In the Limestone Hills the Wolsey shale is about 390 feet thick at locality 1 (pl. 1) and 405 feet thick west of the Stewart quarry. The formation consists primarily of olive and gray mudstone and siltstone, but includes beds of quartzitic sandstone, calcareous sandstone, and silty sandstone. The main quartzitic sandstone beds occur about 35 feet above the base of the unit, and closely resemble those of the Flathead quartzite.

The Wolsey shale, a relatively nonresistant unit, typically forms a shallow swale between the resistant Flathead quartzite and the Meagher limestone.

Detailed stratigraphic section of the Wolsey shale, measured at section locality 1 (pl. 1). $SE\frac{1}{4}$ sec. 34, T. 7 N., R. 1 E.

Meagher limestone:	Feet
26. Limestone, pale yellowish brown to light olive gray, finely crystalline and dense; irregular thin color bands parallel bedding.	74.6
Wolsey shale:	
25. Mudstone, light olive gray, dense, blocky to platy, in irregular beds about 0.04 foot thick; some interbedded fine-grained sandstone or coarse siltstone; unit weathers moderate brown to dark yellowish orange; mildly metamorphosed.	32.8
24. Mudstone, light olive gray to medium dark gray, platy, blocky, or fissile; in part very finely micaceous; in part laminated with laminae conspicuous only on fresh surface; irregular-bedded, with subordinate beds of coarse siltstone or very fine-grained sandstone; unit weathers moderate brown to dark yellowish orange.	22.2
23. Sandstone, quartzitic, very fine-grained.	1.9
22. Concealed.	18.0
21. Mudstone; similar to unit 24.	27.9
20. Concealed.	27.0
19. Sandstone, pale yellowish brown to pale brown, argillaceous, slightly calcareous, very fine-grained, speckled with small limonite grains; in irregular beds averaging 0.1 foot in thickness; locally contains irregular and nonpersistent laminae of dark gray siltstone.	0.9
18. Concealed.	51.3
17. Sandstone; similar to unit 19.	44.2
16. Concealed.	18.9
15. Silstone, gray to grayish black, platy to fissile, coarsely micaceous, laminated; weathers moderate brown.	4.5

		Feet
14.	Concealed.	50.3
13.	Siltstone; similar to unit 15, but medium dark gray and not conspicuously laminated; mildly metamorphosed.	4.9
12.	Concealed.	9.9
11.	Siltstone; similar to unit 13.	4.1
10.	Sandstone, brownish gray, quartzitic, slightly limonitic, very fine-grained.	0.8
9.	Concealed.	12.4
8.	Sill, granodiorite, finely crystalline.	8.5
7.	Sandstone, pinkish gray to pale red, quartzitic, fine-grained; speckled with small limonite grains; sparsely micaceous on some bedding planes; some interbedded gray to grayish black, platy to fissile, coarsely micaceous siltstone.	10.6
6.	Sandstone, pinkish gray to pale red, quartzitic, fine-grained; speckled with small limonite grains; sparsely micaceous on some bedding planes.	13.4
5.	Siltstone, gray, coarse-grained; weathers grayish brown to moderate brown; mildly metamorphosed.	14.4
4.	Concealed.	10.4
3.	Sill, granodiorite, finely crystalline.	4.0
2.	Siltstone, medium gray to dark gray, very micaceous, irregularly laminated with laminae ranging from 0.03 to 0.1 inch in thickness and from medium gray to dark greenish gray; weathers medium dark gray; mildly to moderately metamorphosed.	7.7
	Total thickness of Wolsey shale (excluding sills)	388.5

Flathead quartzite:	Feet
1. Sandstone, grayish orange-pink, grayish pink, and pale red, medium-grained, quartzitic, vitreous, dense, homogeneous; weathers reddish brown, dark yellowish orange, and moderate dark yellowish brown.	3.4

Meagher limestone

The Middle Cambrian Meagher limestone conformably overlies the Wolsey shale. It has a maximum thickness of 416 feet and a minimum thickness of 50 feet in the central Montana-Yellowstone Park region (Deiss, 1936, p. 1331).

In the Limestone Hills the Meagher limestone is approximately 510 feet thick at locality 1 (pl. 1) and approximately 495 feet thick west of the Stewart quarry. The formation may be divided into three fairly distinct units, although the contacts between each of the units are gradational and no sharp dividing lines can be drawn. The basal unit is about 120 feet thick and consists of conspicuously mottled and banded gray limestone. The mottling and banding has a brownish gray to brownish black color near the base but gradually changes in color upward and is dark yellowish orange and yellowish gray near the top. The middle unit is about 150 feet thick and consists of gray limestone, in part mottled or banded with darker shades of gray. This is commonly the most resistant unit of the formation. The upper unit is mottled and banded limestone, somewhat similar to the lower unit, and is about 235 feet thick. The lower 100 feet of this upper unit is mottled with yellowish gray which is not particularly conspicuous; the upper 135 feet is conspicuously mottled with yellowish orange.

The contact of the Meagher limestone with the overlying Park shale was observed at only one locality, the Vermont Marble quarry in sec. 4, T. 6 N., R. 1 E. At this locality, the uppermost part of the formation is as given below.

Detailed partial section of the upper part of the Meagher limestone, measured at Vermont Marble quarry, sec. 4, T. 5 N., R. 1 E.

Meagher limestone:	Feet
4. Limestone, medium dark gray, dense to finely crystalline; concretionary, with disk-shaped concretions up to 0.5 inch in maximum dimension; beds from 0.3 to 0.8 foot thick; yellowish ribbons in middle portion of unit; weathers medium light gray.	3.5
3. Concealed.	1.0
2. Edgewise conglomerate, medium dark gray, finely crystalline flat limestone pebbles up to 2 inches in maximum dimension in a medium dark gray sandy limestone matrix; speckled with yellowish orange particles.	2.0
1. Limestone, medium gray mottled with yellowish orange; gray material is finely crystalline; yellowish orange material is somewhat coarser and is dolomitic; bedding ranges from 0.2 foot to 1.5 feet in thickness; unit weathers medium light gray mottled with pale yellowish orange. Not measured.	

The Meagher limestone forms a low rounded ridge between the shallow valleys of the Wolsey and Park shales (pl. 4A), and commonly is very well exposed in the map area.

The mottling and banding so characteristic of the Meagher limestone in the Limestone Hills appears to differ from that described by Deiss (1936, p. 1331) in the Three Forks region. There the mottles are commonly clayey or silty and occur as chips or fragments and as irregular partings. In the Limestone Hills the mottling is very irregular (pl. 4B) and roughly parallel to the bedding. The mottles are not conspicuously clayey or silty, but rather are composed of dolomitic limestone that is more coarsely crystalline than the finely crystalline, relatively pure gray limestone forming the bulk of the rock. An analysis of the light- and dark-colored portions of the rock, made by Prof. Hartzell of the Montana State School of Mines and furnished the writer by the Vermont Marble Company, is as follows:

No. 1, Segregate of light-colored portion

Insoluble (SiO_2 ?)..........	14.00
Iron and alumina...........	3.30
CaO (31.00) as $CaCO_3$.....	55.34
MgO (12.20) as $MgCO_3$....	25.50
	98.14

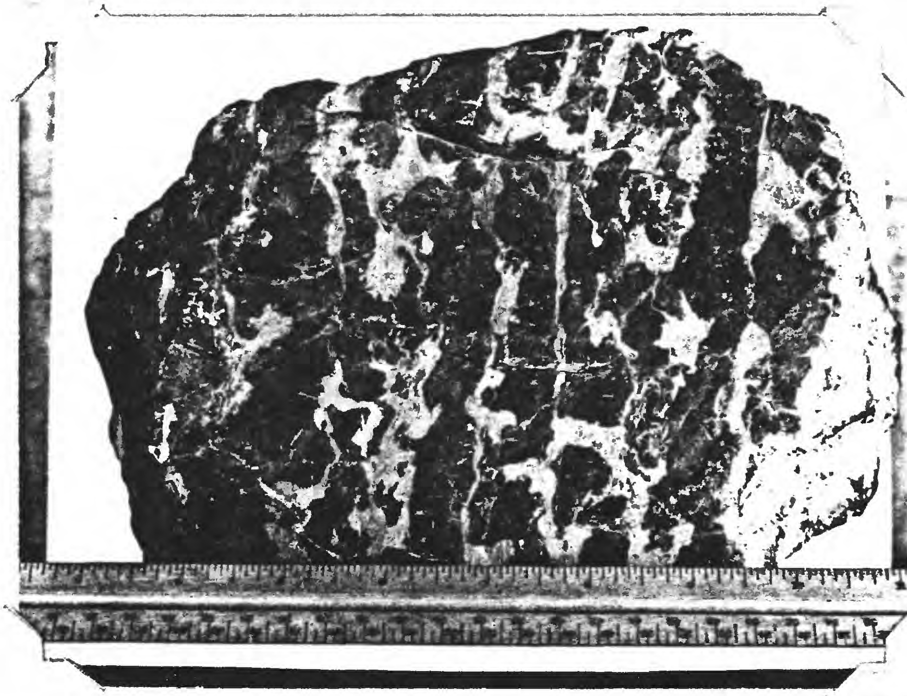
No allowance made for alkalies or moisture.

No. 2, Segregate of dark-colored portion

SiO_2 (?).................	4.75
Iron and alumina..........	2.18
CaO (50.5) as $CaCO_3$......	90.14
MgO (1.25) as $MgCO_3$.....	2.60
	99.67

Plate 4

A. View north into southern Limestone Hills; rounded ridge of Meagher limestone in center; Upper Cambrian dolomite and limestone at left and in background.



B. Typical mottled Meagher limestone.

Iron oxide, probably as limonite pseudomorphic after pyrite, is almost entirely restricted to the light-colored mottled portion, and examination of thin sections from the upper unit of the Meagher shows that zoned dolomite crystals are common in the light-colored portion but absent in the dark-colored portion. The contacts of the light and dark portions are generally gradational, but the gradation takes place over a very short distance and is not always evident.

Both chemical and microscopic evidence suggest that the mottling in the upper and lower units of the Meagher limestone is due to replacement that took place after deposition. The relatively high percentage of insoluble matter (SiO_2 ?) in the light-colored portion is probably syngenetic; it may have exerted some control during replacement by facilitating the passage of replacing solutions.

Detailed stratigraphic section of the Meagher limestone, measured at section locality 1 (pl. 1), SW$\frac{1}{4}$ sec. 34, T. 7 N., R. 1 E.

		Feet
Park shale:		
12.	Concealed, underlain by green fissile shale.	203.9
Meagher limestone:		
11.	Concealed, at least in part underlain by mottled gray and yellowish limestone.	109.6
10.	Limestone, medium gray mottled with yellowish orange; gray part of rock is finely crystalline relatively pure $CaCO_3$, and yellowish orange part is somewhat coarser and is dolomitic; bedding ranges from 0.2 foot to 1.5 feet in thickness; weathers light gray mottled with pale yellowish orange.	24.6
9.	Concealed.	15.2
8.	Limestone, medium gray, finely crystalline; irregularly mottled with yellowish gray dolomitic limestone; contains scattered small chips of limestone that weather in relief in some beds.	87.4
7.	Limestone, light gray to medium light gray, medium-grained and cross-bedded at base; light gray sparsely to very oolitic beds with some medium gray finely crystalline nonoolitic beds in upper part; weathers light gray to medium light gray.	35.0
6.	Limestone, medium gray, very finely crystalline, faintly to conspicuously banded with irregular thin bands of darker, more resistant, probably siliceous limestone; contains twiglike bodies of white calcite; thick- and indistinctly bedded; weathers medium gray with local patches of light and medium gray.	68.5
5.	Limestone, medium dark gray, banded and mottled with medium gray dolomitic limestone that weathers in relief.	46.1
4.	Limestone, medium gray, mottled with yellowish gray; contains irregular, branching, finely crystalline twiglike bodies of dolomite most of which are from 0.02 to 0.05 foot but a few of which exceed 0.1 foot in length; weathers to thick slabs.	10.9

	Feet
3. Limestone, medium gray to medium dark gray, mottled with dark yellowish orange dolomitic limestone that is finely crystalline and occurs in irregular and stringy bodies more or less parallel to bedding and ranging from 0.01 to 0.06 foot in thickness; gray portion weathers to between yellowish gray and pale yellowish orange.	37.7
2. Limestone, pale yellowish brown to light olive gray, finely crystalline and dense; contains dark gray irregular thin bands that weather in relief and probably consist of argillaceous limestone and dolomite; bands are commonly only a few hundredths of a foot thick and separate layers of limestone up to 0.1 foot thick; limestone weathers medium gray to medium light gray with local spots of pale red and pale yellowish brown to moderate black; color of unit gradually changes upward to approach that of unit 3.	74.6
Total thickness of Meagher limestone	509.6
Wolsey shale:	
1. Mudstone, light olive gray, dense, blocky to platy; in irregular beds about 0.04 foot thick; contains a few beds of fine-grained sandstone or coarse siltstone; weathers moderate brown to dark yellowish orange; mildly metamorphosed.	32.8

Park shale

The Park shale is the youngest Middle Cambrian unit in the central Montana-Yellowstone Park region. Wherever the formation is present in this region, its lithology is essentially the same, but its thickness ranges from a maximum of 330 feet to a minimum of 120 feet (Deiss, 1936, pp. 1332-1333).

In the Limestone Hills the Park shale overlies the Meagher limestone with no apparent angular or erosional unconformity. The formation is about 205 feet thick at locality 1 (pl. 1) and 245 feet thick west of the Stewart quarry. The indicated thickness is variable in the mapped area, probably because of thickening and thinning due to structural deformation. The formation is completely concealed in the Limestone Hills, forming a continuous swale between the more resistant limestones and dolomites of the Meagher and Pilgrim limestones. Because of this, its lithology can be inferred only from fragments of float; it appears to consist entirely of olive green fissile, pencilly shale.

Pilgrim limestone

In the central Montana-Yellowstone Park region, the basal Upper Cambrian Pilgrim limestone ranges in thickness from a maximum of 661 feet to a minimum of 172 feet (Deiss, 1936, p. 1334).

In the Limestone Hills, the Pilgrim limestone overlies the Park shale with apparent conformity and at locality 1 (pl. 1) is about 420 feet thick. It can be divided into four lithologic units. The basal unit is about 25 feet thick and consists of gray, finely crystalline, massive limestone. On weathered surfaces, it is inconspicuously mottled with lighter gray. This unit grades into the overlying unit, which is about 165 feet thick and consists of gray limestone ribboned and mottled with yellowish silty dolomite or dolomitic limestone. The third unit, gradational with the ribboned limestones below, is about 80 feet thick and consists of medium light to medium dark gray fine- to medium-crystalline dolomite that is irregularly mottled lighter gray. This mottling is evident only on the weathered surface, and is distinctly linear and more or less parallel to the bedding in the upper half of the unit. The fourth and uppermost unit is gradational with the upper part of the third unit and is about 150 feet thick. It consists of light gray, medium-crystalline, massive homogeneous dolomite.

The ribboned limestone unit and the light gray dolomite unit are the most conspicuous divisions of the Pilgrim—the ribboned limestone because of its distinctive coloration, and the light gray dolomite because of its resistance to weathering. This uppermost unit forms a prominent ridge that extends the length of the Limestone Hills. Plate 5 illustrates the characteristic appearance of the uppermost unit.

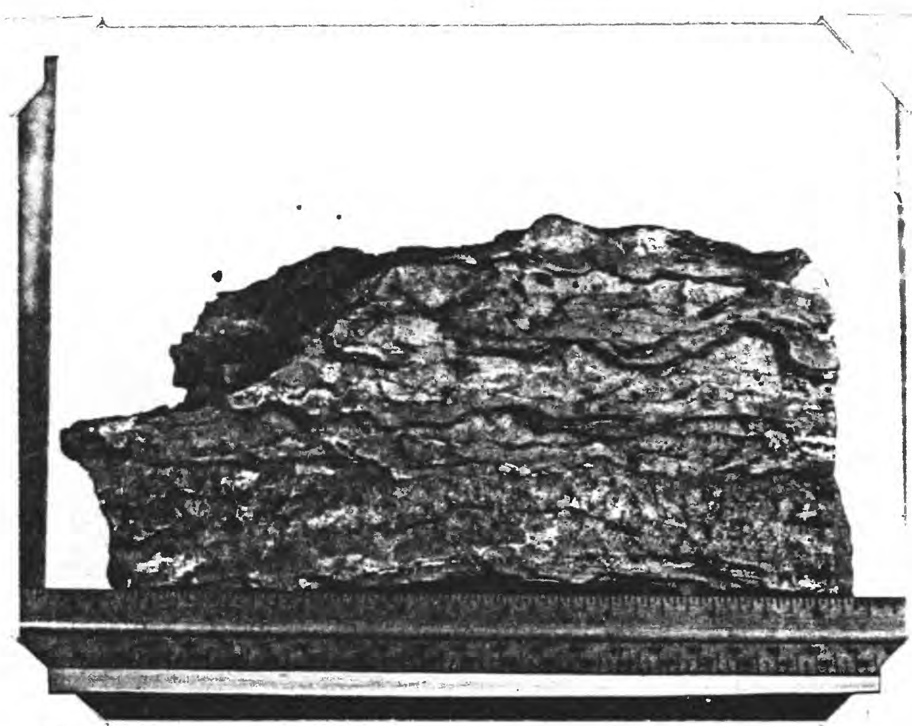
The ribboning and mottling of the second unit is quite different from that of the Meagher Limestone. The ribbons commonly form more or less continuous bands parallel to bedding (pl. 6). They weather in relief, probably because of their silt content. The dolomite is probably a replacement of calcium carbonate; the controlling factor in the replacement may have been the mud and silt deposited with the limestone, which formed zones of slightly greater permeability through which replacing solutions could flow.

Plate 5

A. View north into southern Limestone Hills; uppermost dolomite unit of Pilgrim Limestone in center.

B. View south from NE$\frac{1}{4}$ sec. 4, T. 6 N., R. 1 E.; uppermost dolomite unit of Pilgrim limestone forms center ridge.

Plate 6



Typical lower ribboned limestone of the Pilgrim limestone.

Detailed stratigraphic section of the Pilgrim limestone, measured at section locality 1 (pl. 1), SW$\frac{1}{4}$ sec. 34, T. 7 N., R. 1 E.

Dry Creek (?) shale:	Feet
10. Concealed; in upper 10 feet float is pale red, pale reddish brown, and moderate yellowish brown, chippy to chunky, slightly dolomitic siltstone that weathers light brown, grayish orange pink, and grayish orange; lower 38.8 feet of unit entirely concealed but probably underlain by similar rock.	48.8
Pilgrim limestone:	
9. Dolomite, medium light gray to very light gray, medium-crystalline, homogeneous, thick- and indistinctly bedded; very indistinctly mottled with various shades of gray in lower part; weathers light gray to very light gray and is characteristically a ridge former.	146.7
8. Dolomite, medium gray to medium dark gray, fine- to medium-crystalline, with an irregular, blotchy light gray mottling more or less parallel to bedding, particularly above the middle of the unit; weathers medium gray to medium dark gray.	64.8
7. Concealed.	17.7
6. Limestone, medium light gray to medium dark gray, finely crystalline, massive; banded with ribbons of yellowish gray silty dolomite that form about 30 percent of the total volume of the unit.	24.6
5. Limestone, medium light gray to medium dark gray, finely crystalline; banded with conspicuous ribbons of pale yellowish orange and pale red silty dolomite that form 30 to 35 percent of the total volume of the unit.	80.0
4. Limestone, medium gray, banded with ribbons of light brown to dark yellowish orange silty dolomite that are about 0.01 foot thick and form less than 10 percent of the total unit near the base and that are pale yellowish orange, somewhat thicker and constitute about 30 percent of the rock near the top.	46.0

		Feet
3.	Limestone, medium gray with sparsely scattered intraformational chips near the base and with blotchy yellowish gray ribbons of limestone near the top; unit is transitional into unit 4.	16.5
2.	Limestone, medium gray to medium dark gray, finely crystalline, massive; weathers mottled medium gray and medium light gray with mottling linear near base but becoming blotchy 10 to 15 feet above the base.	25.4
	Total thickness of the Pilgrim limestone	421.7

Park shale:

1.	Concealed, underlain by green, fissile, pencilly shale.	203.9

Dry Creek (?) shale

A unit of Cambrian (?) and Devonian age here referred tentatively to the Dry Creek shale occurs in the central Montana-Yellowstone Park region where it overlies the Pilgrim limestone (Deiss, 1936, pp. 1335-1337). In the Limestone Hills, the contact is apparently conformable.

The Dry Creek (?) shale in the mapped area is about 110 feet thick at locality 2 (pl. 1) and about 80 feet thick west of the Stewart quarry. The formation may be divided into two units: the lower unit is from 37 to 50 feet thick and consists mainly of reddish siltstones, probably with some thin interbedded dolomite beds. The upper 40 to 60 feet of strata is predominantly light colored limestone and dolomite, in part mottled, some beds of which are silty or contain siltstone chips and partings. Neither of these units is particularly resistant, and the rocks characteristically form a swale between the resistant limestones and dolomites of the Pilgrim and Jefferson.

According to Deiss (1936, pp. 1309-1310), the upper part of the Dry Creek shale as commonly mapped in the central Montana-Yellowstone Park region may be of Devonian age. The uppermost known occurrence of Cambrian fossils is at the base of the Dry Creek (Deiss, 1936, p. 1272) and Devonian fossils occur below the top of the formation (Deiss, 1936, p. 1272). Mr. J. S. Williams of the U. S. Geological Survey has made tentative field identifications of Devonian fossils from the upper unit of the Dry Creek (?) shale where it is exposed in Johnny Gulch, sec. 22, T. 5 N., R. 1 W., about 6 miles southwest of the southern end of the Limestone Hills. No fossils were found in the formation in the Limestone Hills, but the lithology of the upper unit is similar to that of the fossiliferous rocks in Johnny Gulch and the upper unit is probably at least partly of Devonian age. The Devonian (?) part of the Dry Creek (?) shale may be equivalent to the basal Devonian unit of Sloss and Laird (1947, pp. 1413-1415).

No unconformity or other boundary suitable for mapping purposes was determined between the upper and lower units of the Dry Creek (?) in the Limestone Hills. The Dry Creek (?) shale as here defined is a distinct and mappable lithologic unit, and the name has been retained in this paper for the rocks between the upper light gray dolomite of the Pilgrim limestone and the basal dark gray Jefferson dolomite.

Detailed stratigraphic section of the Dry Creek (?) shale, measured at section locality 2 (pl. 1), SW$\frac{1}{4}$ sec. 34, T. 7 N., R. 1 E.

	Feet
Jefferson dolomite:	
10. Dolomite, calcareous, or dolomitic limestone, medium dark gray, finely crystalline; in indistinct beds about 6 feet thick, with one bed 3.7 feet thick of yellowish gray to dark yellow limestone at top of unit.	20.6
Dry Creek (?) shale:	
9. Limestone, light olive gray and medium gray to medium light gray, dolomitic, finely crystalline; contains a few breccia layers in upper part; unit weathers yellowish gray to light gray.	14.0
8. Limestone, dolomitic, or calcareous dolomite, medium gray at base and yellowish gray and light gray at top; finely crystalline, massive to medium-bedded; contains sparsely scattered dark yellowish orange siltstone chips near base; weathers to between yellowish gray and light gray.	25.0
7. Limestone, medium light gray, very finely crystalline, dolomitic, platy; contains yellowish gray to grayish yellow bands and mottles up to 1 inch thick, averaging 0.25 to 0.5 inch.	3.0
6. Limestone, pale yellowish orange to grayish orange, dolomitic; medium-bedded and weathers very pale orange at base; thick-bedded and weathers yellowish gray to light gray at top.	8.0
5. Limestone, dolomitic, or calcareous dolomite, yellowish orange, moderately silty, chippy to almost platy; in beds 0.1 to 0.3 foot thick; weathers very pale yellowish orange.	2.5
4. Concealed.	4.0
3. Dolomite, yellowish orange, very finely crystalline; in beds 0.5 to 0.7 foot thick; weathers very pale orange to yellowish orange.	3.0

	Feet
2. Concealed; in upper 10 feet float is pale red, pale reddish brown, and moderate yellowish brown, chippy to chunky, slightly dolomitic siltstone that weathers light brown, grayish orange-pink, and grayish orange; lower 38.8 feet of unit entirely concealed but probably underlain by similar material.	48.8
Total thickness of Dry Creek (?) shale	108.3

Pilgrim limestone:

1. Dolomite, medium light gray to very light gray, medium-crystalline, homogeneous, thick- and indistinctly bedded; very indistinctly mottled with various shades of gray in lower part; weathers light to very light gray and is characteristically a ridge former.	146.7

Devonian System

The Devonian of central and southwestern Montana was first studied in detail by A. C. Peale in 1893. Peale's work in the Three Forks region (1893, pp. 27-32) resulted in the division of Devonian rocks in Montana into two formations--the lower fromation was named the Jefferson dolomite, and the upper formation the Three Forks shale. This division is still accepted. Sloss and Laird (1947, pp. 1413-1415) have since defined, in the Three Forks region, a basal Devonian unit, probably equivalent to the upper unit of the Dry Creek (?) shale of this paper.

Jefferson dolomite

The Upper Devonian Jefferson dolomite (Sloss and Laird, 1947, pp. 1427-1428) overlies the Dry Creek (?) shale with apparent conformity in the Limestone Hills. The formation is about 475 feet thick and is composed preponderantly of medium gray to dark gray fetid dolomite, although limestone beds, some of which are silty or dolomitic, are present. Breccia zones of probable sedimentary origin are fairly common.

In the Limestone Hills the Jefferson dolomite forms a low secondary ridge (pl. 7) on the western slope of the prominent ridge of Pilgrim limestone and commonly crops out over the entire western slope of this ridge.

Plate 7

View northeast from NE$\frac{1}{4}$ sec. 4, T. 6 N., R. 1 E.; ridge of Jefferson dolomite to left; ridge of Pilgrim dolomite to right.

Detailed stratigraphic section of the Jefferson dolomite, measured at section locality 2 (pl. 1), SW$\frac{1}{4}$ sec. 34, T. 7 N., R. 1 E.

	Feet
Three Forks shale:	
25. Concealed.	60.1
Jefferson dolomite:	
24. Dolomite, medium gray to medium dark gray, finely crystalline, fetid, thick- and indistinctly bedded; contains scattered pseudomorphs of iron oxide after pyrite 2 to 6 feet below top of unit.	10.0
23. Dolomite, medium gray, finely crystalline, laminated with bands of slightly different color commonly less than 0.04 inch thick; in part platy, in beds from 0.5 to 0.8 foot thick; weathers medium light gray to medium gray.	32.0
22. Concealed, underlain by medium dark gray to dark gray, finely crystalline, fetid dolomite; thin calcite seams common.	34.2
21. Concealed, abundant chips of yellowish orange silty dolomitic limestone occur in soil in upper 10 to 15 feet of unit; one bed of yellowish gray to medium light gray limestone or dolomitic limestone occurs about 22 feet above the base of the unit.	37.2
20. Dolomite, medium dark gray to dark gray, finely crystalline; contains inconspicuous calcite seams and sporadic patches or clusters of crystalline calcite; thick- and indistinctly bedded at base becoming distinctly medium-bedded in middle of unit.	30.7
19. Concealed, one bed 2 feet thick of medium dark gray dolomite from 23.4 to 25.4 feet above the base of the unit.	32.1
18. Dolomite, medium gray, finely crystalline; a lenticular bed of intraformational conglomerate 0.5 to 1 foot thick composed of mixed dolomite fragments occurs from 4.5 to 5.5 feet above the base of the unit.	6.7
17. Concealed.	4.8

		Feet
16.	Dolomite, dark gray, finely crystalline, fetid, distinctly bedded.	23.8
15.	Concealed.	4.7
14.	Dolomite, light to medium light gray, finely crystalline, fetid, indistinctly bedded; contains lenticular breccia zone composed of fragments of similar dolomite up to 3 inches in maximum dimension.	1.6
13.	Dolomite, dark gray, finely crystalline, very fetid; distinct beds from 0.7 foot to 2 feet thick; contains some interbeds of medium gray to medium light gray dolomite; weathered surface rough.	18.7
12.	Dolomite, light gray and medium gray; contains interbeds of similarly colored calcareous dolomite; unit thick- and indistinctly bedded; predominantly light gray in lower 8 to 12 feet, darker in upper 10 feet.	23.8
11.	Dolomite, medium gray; indistinct beds from 0.7 foot to 2 feet thick; conspicuous color banding from 33.4 to 36.0 feet above the base of the unit; a 5-foot concealed zone from 2.1 to 7.1 feet above base; weathers variably from medium light to medium gray with a few scattered irregular to ovoid siliceous encrustations on weathered surfaces.	30.1
10.	Concealed, abundant dark dolomite and yellowish orange silty dolomitic limestone chips in soil.	9.1
9.	Dolomite, medium dark gray, finely crystalline, distinctly bedded in beds 0.7 to 1 foot thick; locally contains a few calcite stringers less than 0.05 inch thick; weathers to rough medium dark to dark gray surface.	10.6
8.	Dolomite, medium gray.	2.1
7.	Dolomite, similar to unit 9, with irregular branching markings as much as 2 inches long and 0.5 inch wide at the base of the unit.	4.3
6.	Dolomite; similar to unit 9.	32.5
5.	Limestone, medium gray, finely crystalline; contains two thin dolomite beds; weathers medium gray to medium light gray.	32.6

	Feet
4. Dolomite, medium dark gray in lower 10.3 feet, medium gray in upper 14.2 feet, finely crystalline; contains scattered small siliceous patches on weathered surfaces; unit weathers medium dark gray in lower 10.3 feet and medium gray to medium light gray in upper 14.2 feet.	24.5
3. Dolomite, medium dark gray, commonly thick- and indistinctly bedded; contains siliceous zone from 19.7 to 23.7 feet above the base of the unit.	49.7
2. Dolomite, calcareous or dolomitic limestone, medium dark gray, finely crystalline, in indistinct beds about 6 feet thick; at top of unit is one bed 3.7 feet thick of yellowish gray to dark yellow limestone.	20.6
Total thickness of Jefferson dolomite	476.3
Dry Creek (?) shale:	
1. Limestone, light olive gray and medium gray to medium light gray, dolomitic, finely crystalline; contains a few breccia layers in upper part; unit weathers yellowish gray to light gray.	14.0

Three Forks shale

The Three Forks shale of Upper Devonian age (Sloss and Laird, 1947, p. 1428) overlies the Jefferson dolomite with apparent conformity in the Limestone Hills. The formation is the youngest Devonian unit present in the central Montana-Yellowstone Park region. In the Three Forks region it is about 200 feet thick (Berry, 1943, p. 14).

In the Limestone Hills, the Three Forks shale is about 360 feet thick. At locality 2 (pl. 1), the lower 280 feet of the formation consists of poorly exposed gray very fissile, papery to pencilly shale. The upper 80 feet, which is slightly better exposed, consists almost entirely of yellowish calcareous siltstone with subordinate beds of light gray silty limestone. Several sills, including the large centrally located sill, have been intruded into the formation.

Detailed stratigraphic section of the Three Forks shale, measured at section locality 2 (pl. 1), SE$\frac{1}{4}$ sec. 33, T. 7 N., R. 1 E.

Lodgepole limestone:		Feet
23.	Limestone, medium dark gray, dense to medium-crystalline, except lower 4 feet which is coarsely crystalline and very fossiliferous; in part distinctly bedded in beds from 0.1 to 1 foot, averaging 0.2 to 0.3 foot thick; in part with a hackly fracture more or less parallel to bedding; weathers medium gray with a bluish and in part a yellowish tint.	144.7
Three Forks shale:		
22.	Sill, granodiorite.	1.6
21.	Siltstone, very calcareous, medium gray, almost fissile.	8.5
20.	Siltstone, very calcareous, poorly fissile; weathers between pale yellowish orange and moderate yellowish brown with pale red and medium gray patches.	4.2
19.	Limestone, medium gray to medium light gray, finely crystalline, silty, thinly but conspicuously laminated; weathers light olive gray.	0.3
18.	Siltstone; similar to unit 20.	0.8
17.	Sill, granodiorite.	4.2
16.	Siltstone; similar to unit 20.	14.4
15.	Siltstone, very calcareous, fissile, weathers between pale yellowish orange and moderate yellowish brown with pale red and medium gray patches.	8.5
14.	Concealed.	10.2
13.	Siltstone, yellowish gray, moderately calcareous, thinly platy to fissile.	4.2
12.	Concealed.	16.0
11.	Limestone, medium light gray with irregular yellowish orange areas; crumbly, in part blocky, in part fissile; contains abundant fossil fragments.	3.4

		Feet
10.	Concealed.	6.8
9.	Sill, covered by granodiorite float.	5.0
8.	Concealed.	104.1
7.	Concealed; predominantly gray, fissile shale float.	42.0
6.	Shale, dark gray, extremely fissile, papery; finely pencilly near top of unit; contains some 0.3 to 0.4 foot beds of moderate yellowish brown, moderately calcareous, sparsely pyritic, coarse-grained siltstone.	19.2
5.	Concealed; gray papery shale float similar to the shale in unit 6.	27.8
4.	Shale, similar to shale in unit 6 but medium dark gray.	15.7
3.	Concealed; gray papery shale float similar to that in unit 6.	12.5
2.	Concealed.	60.1
	Total thickness of Three Forks shale (excluding sills)	358.7

Jefferson dolomite:

1.	Dolomite, medium gray to medium dark gray, finely crystalline, fetid, thick- and indistinctly bedded; contains scattered pseudomorphs of iron oxide after pyrite 2 to 6 feet below top of unit.	10.0

Carboniferous System

Mississippian series

Madison Group

The Madison limestone was named and first described by A. C. Peale (1893, pp. 32-39), who considered it a formation and divided it into three lithologic units. These three units were later correlated by Weed (1900, pp. 290-294) with the lower Carboniferous Paine shale, Woodhurst limestone, and Castle limestone of central Montana.

In 1922 Collier and Cathcart (p. 173) raised the Madison limestone in the vicinity of the Little Rocky Mountains to the status of a group and subdivided it into two formations--the Lodgepole and the Mission Canyon limestones, both of lower Mississippian age. The Madison group in central and southwestern Montana is now divided either into the Lodgepole and Mission Canyon limestones or into the lower Madison and upper Madison limestones.

The lithology of the Madison group in the Limestone Hills is similar to that described by Collier and Cathcart (1922, p. 173) in the Little Rocky Mountains. For this reason, the writer has followed Collier and Cathcart's terminology for the occurrence in the Limestone Hills.

Mr. J. S. Williams of the U. S. Geological Survey made tentative field identifications of Upper Mississippian fossils from the upper 150 to 200 feet of the Mission Canyon limestone in the SE$\frac{1}{4}$ sec. 29, T. 6 N., R. 1 E., indicating that this part of the Mission Canyon in the Limestone Hills may be equivalent in age to part of the Upper Mississippian Brazer limestone of northeastern Utah (Richardson, 1913, p. 413).

Lodgepole limestone.--The Lodgepole limestone in the Limestone Hills overlies, with apparent conformity, the Three Forks shale. It is about 595 feet thick at locality 2 (pl. 1) and 650 feet thick at the southern end of the Hills. It consists mainly of gray, thin- to medium-bedded limestone, many beds of which are fossiliferous. The upper part of the formation is gradational into the massive limestone of the Mission Canyon, and placement of the contact is therefore interpretive. Where possible in the Limestone Hills, it was placed below the first massive or thick- and indistinctly bedded limestone above the thin-bedded limestone of the Lodgepole. Two measured sections of the Lodgepole limestone are described below; in the second of these, the transition zone between the Lodgepole and the Mission Canyon limestones is indicated.

Detailed stratigraphic section of the Lodgepole limestone, measured at section locality 2 (pl. 1), $SE\frac{1}{4}$ sec. 33, T. 7 N., R. 1 E.

Mission Canyon limestone:	Feet
15. Limestone, medium light gray, variably crystalline, massive to thick- and indistinctly bedded; contains sparse, small, dark, probably siliceous, rods near base of unit; weathers medium light gray with irregular patches of medium gray.	41.4
Lodgepole limestone:	
14. Concealed; gray, thin-bedded limestone float.	33.7
13. Limestone, medium light gray, medium- to coarse-crystalline, indistinct beds from 1 foot to 2 feet thick; weathers light gray to medium light gray.	21.3
12. Limestone, medium light gray, finely crystalline; in part hackly; in beds 0.2 to 0.5 foot thick, with yellowish gray clayey partings; weathers light to medium light gray.	10.4
11. Concealed.	26.0
10. Limestone, medium light gray, finely crystalline, indistinct beds 0.5 foot to 2 feet thick; locally more coarsely crystalline and fossiliferous; local siliceous encrustations on weathered surface.	25.1
9. Limestone, medium gray, finely crystalline, sparsely fossiliferous, in beds from 0.1 to 0.3 foot thick; in upper 32 feet beds have a yellowish gray tint, are separated by clayey partings, and contain scattered thin siliceous encrustations parallel to bedding.	58.4
8. Limestone, medium gray with bluish tint, coarsely crystalline; in beds 0.5 to 0.7 foot thick separated by clayey partings.	50.0
7. Limestone, medium gray with bluish tint, finely crystalline, fossiliferous; in fairly distinct beds about 0.5 foot thick, with numerous irregular calcite seams and yellowish gray and pale red branching clayey partings; contains some medium- to coarse-crystalline, very fossiliferous beds in the	

	Feet
upper 24 feet; bed 4.8 feet thick with very abundant corals and brachiopods occurs from 3.8 to 8.6 feet above the base of the unit.	96.1
6. Limestone, medium dark gray, very finely to finely crystalline, distinctly bedded in thin to medium beds; in part thinly laminated; fossiliferous beds containing horn corals and brachiopods 54.5 feet above base; weathers medium gray with a bluish tint and locally with a yellowish tint; siliceous encrustations on the weathered surfaces of some beds.	112.5
5. Sill, granodiorite.	6.5
4. Concealed.	14.9
3. Limestone, medium dark gray, dense to medium-crystalline; lower 4 feet coarsely crystalline and very fossiliferous; distinctly bedded in beds from 0.1 to 1 and averaging 0.2 to 0.4 foot in thickness; in part thinly laminated; in part with a hackly fracture more or less parallel to bedding; weathers medium gray with a bluish and in part a yellowish tint.	144.7
Total thickness of the Lodgepole limestone (excluding sill)	593.1
Three Forks shale:	
2. Sill, granodiorite.	1.6
1. Siltstone, very calcareous, medium gray, almost fissile.	8.5

Detailed stratigraphic section of the Lodgepole limestone,
measured in SW$\frac{1}{4}$ sec. 33, T. 6 N., R. 1 E.,
by M. R. Klepper, 1948

Mission Canyon limestone:	Feet
35. Limestone, medium light gray, massive.	----
Lodgepole limestone:	
Top of transition zone Lodgepole and Mission Canyon limestones:	
34. Concealed.	16.4
33. Limestone, weathers gray and bluish gray; contains irregular pale yellowish brown silty laminae.	19.1
32. Limestone, weathers gray and bluish gray; contains pale red and yellowish laminae.	13.6
Base of transition zone Lodgepole and Mission Canyon limestones:	
31. Limestone, gray, dense, finely crystalline; contains irregular silty laminae spaced 0.1 to 0.5 foot apart; weathers mottled medium to light gray with a bluish tint; silty laminae weather yellowish gray, grayish yellow, light brownish gray, and pale red.	31.1
30. Concealed.	9.5
29. Limestone, bluish gray, dense, and interbedded gray, crystalline, punky limestone; in beds averaging about 0.3 foot in thickness.	4.0
28. Concealed.	5.2
27. Limestone, gray, crystalline, punky; contains abundant crinoid fragments.	1.6
26. Concealed; bluish gray limestone float.	19.9
25. Limestone, weathers gray and bluish gray; contains thin and sparse grayish yellow to very pale yellowish orange irregular silty laminae.	8.4
24. Limestone, dense, indistinctly bedded; contains irregular silty laminations; weathers mottled gray and bluish gray.	14.9
23. Concealed.	30.6

		Feet
22.	Limestone, interbedded dense and coarsely crystalline, in beds up to 2 feet thick; unit weathers to mottled gray and bluish gray surface which is rougher than typical weathered Lodgepole limestone.	18.7
21.	Concealed; bluish gray limestone float.	29.3
20.	Limestone, medium dark gray, dense, in indistinct beds 0.25 to 1 foot thick; weathers light gray to medium light gray, with a slight bluish tint in the upper 5 feet.	12.8
19.	Limestone, in beds up to 0.7 foot and averaging 0.2 to 0.3 foot in thickness; weathers bluish gray.	136.3
18.	Limestone, dense, in beds up to 1 foot and averaging 0.25 to 0.5 foot in thickness; weathers bluish gray.	128.1
17.	Concealed.	6.9
16.	Limestone, dark gray with bluish tint; dense, in beds 0.04 to 0.3 foot thick; weathers light bluish gray.	21.5
15.	Concealed.	2.6
14.	Limestone, gray to olive gray, impure.	3.4
13.	Limestone, crystalline, punky, fossiliferous; weathers gray, bluish gray, and olive gray.	6.0
12.	Concealed.	9.2
11.	Limestone, dense; weathers bluish gray.	32.0
10.	Limestone, in beds averaging 0.3 foot in thickness; prominent chert lenses elongated parallel to bedding occur in central part of unit; weathers bluish gray.	4.0
9.	Concealed; thin-bedded bluish gray limestone float.	13.0
8.	Limestone, mottled dark and light gray, coarsely crystalline; contains some poorly preserved brachiopod fragments; weathers medium gray.	1.5
7.	Concealed.	24.5

		Feet
6.	Limestone, medium to medium dark gray with greenish tint, very silty, fissile to platy; weathers medium gray to medium light gray.	1.0
5.	Concealed.	7.0
4.	Limestone, medium olive gray, silty; weathers to slightly lighter and more brownish color.	2.0
3.	Concealed.	10.0
2.	Limestone, weathers bluish gray.	2.0
1.	Limestone, dark gray, dense, dolomitic; weathers medium gray with bluish tint.	2.4
	Total thickness of the Lodgepole limestone (including transition zone Lodgepole and Mission Canyon limestone)	648.5

Mission Canyon limestone. --The thin-bedded Lodgepole limestone grades upward into the thick- and less distinctly bedded Mission Canyon limestone over a thickness of at least 50 feet. The contact can usually be located with reasonable accuracy in the Limestone Hills if care is taken to locate the first massive or thick- and indistinctly bedded limestone above the thin-bedded Lodgepole limestone, but in the region southwest of the Limestone Hills the contact is typically so gradational that it can be placed only within 200 or 300 feet.

At locality 5 (pl. 1) in the southern part of the Limestone Hills, the Mission Canyon limestone is 1,105 feet thick. Throughout the mapped area it consists of medium gray to light gray, finely to coarsely crystalline, thick- and indistinctly bedded or massive limestone. Solution breccias are common in the upper third of the formation and most appear to be lenticular, although individual lenses may have considerable lateral extent.

The limestone characteristically weathers to an extremely rough surface. The weathered surface may be pitted or it may be grooved by solution channels, sometimes more than an inch deep, which parallel the direction of slope. Caliche-like crusts, which are common on weathered surfaces, apparently form by redeposition of previously dissolved calcium carbonate. Where these crusts have been precipitated, the surface has a blotchy or patchy appearance.

The Mission Canyon limestone in the Limestone Hills is not conspicuously cherty, but siliceous encrustations that weather in relief and closely resemble chert are fairly abundant in certain beds. The encrustations are thin and surround a core of normal limestone. They are probably formed by concentration of residual silica during the weathering of the more siliceous layers of limestone.

Detailed stratigraphic section of the Mission Canyon limestone, measured at section locality 5 (pl. 1), $SE\frac{1}{4}$ sec. 29, T. 6 N., R. 1 E.

		Feet
Amsden formation:		
42.	Concealed, red siltstone float.	99.1
Mission Canyon limestone:		
41.	Limestone, medium gray to medium light gray, finely crystalline, slightly fetid, massive; sporadic siliceous encrustations on weathered surface; top of unit marked by a bed of limestone breccia 0.2 to 1 foot thick; unit weathers light gray to medium light gray.	56.1
40.	Breccia, limestone and siltstone fragments in a limestone matrix.	7.8
39.	Concealed.	10.6
38.	Limestone, medium gray to medium light gray, finely crystalline, slightly fetid; contains sparse chert lenses and lumps; weathers light gray to medium light gray.	8.7
37.	Limestone, medium gray to medium light gray, medium coarsely to coarsely crystalline, slightly fetid, thick- and indistinctly bedded; sparse lumpy siliceous encrustations occur along bedding; weathers to rounded but rough and pitted light gray to medium light gray outcrops.	12.6
36.	Concealed, moderately abundant float chips of yellowish gray calcareous siltstone possibly underlain by breccia unit similar to unit 40.	28.1
35.	Limestone, similar to unit 37 but not siliceous.	32.3
34.	Limestone, medium light gray, finely to very finely crystalline, moderately fetid, massive; contains abundant small, clear crystalline calcite twigs; weathers to very rough patchy surface colored medium light gray and medium light gray with yellowish tint.	31.4

	Feet
33. Limestone, medium gray to medium light gray, medium coarsely to coarsely crystalline, slightly fetid; contains three conspicuous chert lenses averaging 0.08 foot in thickness and from 1 to 3 feet apart; unit weathers light gray to medium light gray.	5.5
32. Limestone, medium gray to medium light gray, fine- to medium-crystalline; weathers medium dark gray.	22.8
31. Limestone, medium gray to medium light gray, finely crystalline, slightly fetid; contains sparsely scattered angular chert fragments; weathers light gray to medium light gray.	7.9
30. Limestone, medium gray to medium light gray, finely crystalline; contains sparsely dispersed irregular small lumps and bands of chert; weathers light gray to medium light gray.	4.6
29. Concealed, probably underlain by limestone breccia.	71.1
28. Limestone, medium light gray to medium gray, finely to coarsely crystalline, slightly fetid; contains irregular lenticular to streaky moderate brown weathering siliceous bands and ribs that roughly parallel bedding and form less than 5 percent of the outcrop surface; weathers light gray to medium light gray.	17.9
27. Limestone, medium gray to medium light gray, finely crystalline, slightly fetid, thick- and indistinctly bedded; weathers to rough and pitted surface colored light gray to medium light gray.	26.9
26. Limestone; similar to unit 28.	11.2
25. Limestone, medium gray to medium light gray, medium coarsely to coarsely crystalline, slightly fetid, thick- and indistinctly bedded; contains some siliceous bands in the upper 10 feet similar to those in unit 28; weathers light gray to medium light gray with a rough and pitted surface.	55.8
24. Limestone, similar to unit 25, but with irregular siliceous encrustations.	6.2

		Feet
23.	Limestone, similar to unit 25, but with moderately sparse small bedding lenses and irregular pods of medium dark gray chert that weathers dark yellowish brown.	10.3
22.	Limestone, medium gray to medium light gray, finely crystalline; contains a few small siliceous encrustations; breccia zone 3.5 feet thick occurs from 8 to 11.5 feet above the base of the unit; weathers to light gray or medium light gray rough and pitted surface.	79.0
21.	Limestone, light gray, very finely crystalline, moderately fetid, massive; small clear crystalline calcite twigs abundant; sparse siliceous encrustations; weathers to patchy very rough surface colored medium light gray and medium light gray with yellowish tint.	9.1
20.	Concealed.	35.5
19.	Limestone, similar to unit 21, but without conspicuous calcite twigs.	2.7
18.	Concealed.	22.1
17.	Limestone breccia, limestone matrix with subangular to subrounded pebbles up to 1 inch in maximum dimension of limestone similar to that in unit 22.	3.6
16.	Concealed.	22.1
15.	Limestone, light gray, very finely crystalline, moderately fetid, massive; small clear crystalline calcite twigs abundant except in upper 8 feet of unit; weathers to a patchy very rough surface colored medium light gray and medium light gray with yellowish tint.	140.3
14.	Limestone, medium gray to medium light gray, medium coarsely to coarsely crystalline, slightly fetid, thick- and indistinctly bedded; weathers to a light gray to medium light gray rough and pitted surface.	13.7
13.	Limestone, similar to unit 14, but medium- to finely crystalline and thick- but distinctly bedded.	21.6

		Feet
12.	Concealed.	10.1
11.	Limestone, medium gray to medium light gray, medium coarsely to coarsely crystalline, slightly fetid, massive; weathers to a patchy very rough surface colored medium light gray and light olive gray.	41.8
10.	Concealed.	9.6
9.	Limestone, medium gray to medium light gray, medium coarsely to coarsely crystalline, slightly fetid, thick- and indistinctly bedded; abundant angular fragments of siliceous limestone weather in relief; weathers to a light gray to medium light gray rough and pitted surface.	13.1
8.	Limestone, medium gray to medium light gray, finely to coarsely crystalline, slightly fetid, thick- and indistinctly bedded; contains irregular lenticular to streaky siliceous ribs which roughly parallel bedding; ribs in upper 16 feet of unit are thicker and more continuous, ranging up to 0.3 foot in thickness and occurring at intervals of from 0.2 foot to 4 feet; unit weathers to a light gray to medium light gray rough and pitted surface.	104.2
7.	Limestone, medium gray, medium coarsely to coarsely crystalline, slightly fetid, thick- and indistinctly bedded; weathers to a medium light gray rough and pitted surface.	10.0
6.	Concealed.	11.0
5.	Limestone; similar to unit 7.	22.0
4.	Limestone, medium gray to medium light gray, medium coarsely to coarsely crystalline, slightly fetid, thick- and indistinctly bedded; contains large horn corals about 25 feet above base of unit; weathers to a rough and pitted light gray to medium light gray surface.	74.0
3.	Concealed.	22.3

	Feet
2. Limestone, medium gray to medium light gray, coarsely crystalline, in medium to thick and indistinct beds; locally contains fragments of corals and brachiopods; irregular clayey partings occur in upper 9 feet; weathers medium light gray.	21.5
Total thickness of the Mission Canyon limestone	1,105.0
Lodgepole limestone:	
1. Limestone, medium light gray, thin- and indistinctly bedded; contains irregular yellow, light olive gray and, less commonly, pale red clayey partings.	8.4

Mississippian and Pennsylvanian series

Amsden Formation

The Amsden formation was named in 1904 by N. H. Darton (pp. 396-397) for exposures near Dayton, Wyoming, but was not recognized in the central Montana-Yellowstone Park region until 1935 (Scott, pp. 1013-1014). Prior to 1935, the formation in this region had been included in the overlying Pennsylvanian Quadrant formation in accordance with Peale's description of the Quadrant formation in the Three Forks region (1893, pp. 39-43) and in the description of the Quadrant at its type locality on Quadrant Mountain in Yellowstone Park (Weed, 1896, p. 5). The formation includes rocks of Mississippian and Pennsylvanian age in the central Montana-Yellowstone Park region.

Scott (1935, p. 1023) determined the age of the Amsden formation as middle or upper Chester, but Berry (1943, p. 19) has since identified fossils of Pennsylvanian age from the upper 100 feet of the Amsden in the Three Forks-Logan region. It is probable that the upper part of the formation in the Three Forks-Yellowstone Park region and in the Limestone Hills is of Pennsylvanian age.

In the Limestone Hills, the Amsden formation overlies the Mission Canyon limestone with apparent conformity and grades upward into the Pennsylvanian Quadrant formation over a thickness of about 60 feet. Throughout the mapped area, the upper contact was placed at the lowest bed of vitreous quartzite or, if exposures were poor, at the upper limit of reddish siltstone float and reddish soil; the lowest quartzite bed and the upper limit of reddish soil are at approximately the same stratigraphic position.

The Amsden formation is about 260 feet thick at locality 5 (pl. 1). Here it consists of reddish, commonly calcareous siltstone with a conspicuous limestone and dolomite unit from about 75 to 110 feet below the top. The formation characteristically forms a swale between the resistant Mission Canyon limestone and the quartzite of the Quadrant formation.

Detailed stratigraphic section of the Amsden formation, measured at section locality 5 (pl. 1), SE$\frac{1}{4}$ sec. 29, T. 6 N., R. 1 E.

	Feet
Quadrant formation:	
12. Quartzite, light gray to medium light gray, clean, vitreous, fine-grained; weathers yellowish brown.	1.0
Amsden formation:	
11. Concealed.	35.0
10. Concealed; reddish soil.	25.2
9. Concealed; abundant chips of moderate red to pale reddish brown siltstone; reddish soil.	12.9
8. Dolomite, medium light gray, finely crystalline; one 0.3-foot bed of intraformational breccia occurs 4 feet above base of unit.	9.9
7. Concealed.	3.0
6. Limestone, light gray to light olive gray; medium finely crystalline; contains sporadic small calcite crystals and fossil fragments.	2.0
5. Concealed.	22.8
4. Limestone, medium light gray, very finely crystalline, in beds from 0.7 to 1 foot thick; contains sporadic chert nodules up to 0.3 foot in diameter.	3.0
3. Concealed.	45.6
2. Concealed; red siltstone float.	99.1
Total thickness of the Amsden formation	258.5
Mission Canyon limestone:	
1. Limestone, medium gray to medium light gray, finely crystalline, slightly fetid, massive; contains sporadic siliceous encrustations; top of unit marked by a bed of limestone breccia 0.2 to 1 foot thick; weathers light gray to medium light gray.	56.1

Pennsylvanian series

Quadrant Formation

The Pennsylvanian rocks of the Three Forks-Yellowstone Park region were first studied in the vicinity of Three Forks, and it was in Peale's report on this area (1893, pp. 39-43) that the name Quadrant was applied to all the rocks between the Mississippian Madison limestone and the Jurassic Ellis formation. However, the Quadrant was not defined at its type locality on Quadrant Mountain in Yellowstone Park until 1896 (Weed, p. 5). Weed's definition of the formation included only rocks between the Madison limestone and the Permian and Triassic Teton formation, but Peale's original definition in the Three Forks region continued to be applied in the Three Forks-Yellowstone Park region until 1918, when Condit (p. 113) restricted the formation to the rocks lying between the Madison limestone and Permian Phosphoria formation. Scott (1935, pp. 1013-1014) further restricted the Quadrant formation by calling the basal 109 feet of the formation at its type locality Amsden.

The Quadrant formation is 230 feet thick at its type locality on Quadrant Mountain in Yellowstone Park. It wedges out 5 miles northeast of Lombard, Montana, but is present to the northwest in the vicinity of Helena and over most of west central and southwestern Montana (Scott, 1935, p. 1015).

In the Limestone Hills the formation is gradational from the underlying Amsden formation. At locality 4 (pl. 1) it is about 325 feet thick and consists of alternating yellowish brown quartzite and quartzitic sandstone and gray dolomite beds, some of which are cherty. Dolomite is predominant in the lower half of the formation and quartzite in the upper half.

The lower 100 to 150 feet of the Quadrant formation as mapped and described in the Limestone Hills is probably equivalent to the upper 100 to 150 feet of the Amsden formation in the Three Forks region described by Sloss (Sloss, et. al., 1946, pp. 13-14); however, in the Limestone Hills and elsewhere in the Radersburg quadrangle where the writer has observed the Amsden and Quadrant formations, the strata in question seem to be lithologically more closely related to the overlying unquestioned Quadrant than to the underlying, predominantly red, Amsden.

Permian System

Phosphoria formation

Permian rocks in the northeastern Utah-southwestern Montana region are assigned to the Phosphoria formation. This formation, which was first described and named by Mansfield and Richards (1912, pp. 684-689) from its exposure in Phosphoria Gulch, near Meade Park, Idaho, has since been recognized over a considerable area in southwestern Montana. In the Three Forks region it is about 70 feet thick and consists of quartzite and chert with some thin phosphatic zones

(Berry, 1943, p. 20). The Phosphoria feathers out to the northeast of a line drawn from Helena, Montana, through a point about 20 miles west of the Limestone Hills to the northwest corner of Yellowstone Park (Condit, 1918, p. 113).

The Phosphoria formation in the Limestone Hills overlies the Quadrant formation with apparent conformity. It is about 45 feet thick at locality 5 (pl. 1), where it consists of 35 feet of yellow to gray chert overlain by 10 feet of yellowish brown quartzite. Phosphatic fragments and chips occur in the upper quartzite unit about 5 to 9 feet below the top of the formation.

Because of the thinness of the Permian Phosphoria formation in the area studied, it was impractical to map it as a separate unit. Therefore, the Quadrant and Phosphoria formations were mapped together.

Detailed stratigraphic section of the Quadrant and Phosphoria formations, measured at section locality 4 (pl. 1), NW$\frac{1}{4}$ sec. 29, T. 6 N., R. 1 E.

	Feet
Swift sandstone:	
41. Sandstone, moderate brown to dark yellowish brown, silty, somewhat limonitic, medium-grained; weathers dark yellowish brown.	5.0
40. Conglomerate, rounded chert and quartzite pebbles up to 3 inches in diameter in a sandy matrix.	1.0
UNCONFORMITY	
Phosphoria formation:	
39. Quartzite, pale yellowish brown, very slightly limonitic, medium fine-grained; contains phosphatic fragments and chips in lower half and small chert nodules in upper half.	8.5
38. Dolomite, medium gray, medium-crystalline.	0.5
37. Quartzite, homogeneous, very fine-grained; gradational from unit 36.	1.0
36. Chert, appears fragmental to nodular when weathered; in part quartzitic; upper 4.3 feet probably very fine-grained quartzite containing some small chert fragments.	9.3
35. Concealed.	2.9
34. Chert, pale yellowish brown; weathers to very irregular surface.	0.7
33. Concealed.	6.4
32. Chert, olive gray, somewhat sandy, weathered surfaces appear fragmental to nodular.	3.2
31. Quartzite, medium gray, fine-grained, indistinctly bedded.	6.8
30. Chert, light brown to dark yellowish orange, chunky; contains small ovoids or spheroids of quartz.	5.0
Total thickness of the Phosphoria formation	44.3

Quadrant formation:	Feet
29. Concealed.	18.9
28. Dolomite, medium light gray to medium gray, fine- to medium-crystalline or granular; weathers medium light gray to light gray.	4.6
27. Concealed.	44.7
26. Quartzite, pale orange, clean, vitreous, fine-grained, thick- and indistinctly bedded.	16.0
25. Dolomite, similar to unit 28, but sparsely sandy and with a very irregular upper surface probably due to channeling prior to deposition of the overlying quartzite bed.	3.0
24. Quartzite, similar to unit 26, but with sparse nodules and thin lenticular beds of chert.	14.0
23. Dolomite, similar to unit 28, but slightly more calcareous.	5.0
22. Quartzite; similar to unit 26.	9.0
21. Dolomite, similar to unit 28, but contains sporadic irregular to subrounded chert nodules in central part and a few siliceous partings and one 0.5 foot bed of calcareous punky sandstone in upper half; contains poorly defined siliceous ribs more or less parallel to bedding in upper 4 feet.	22.0
20. Quartzite, pale yellowish brown, clean, vitreous, fine-grained, thick- and indistinctly bedded.	16.0
19. Dolomite, similar to unit 28, but contains near the base a few siliceous crusts or partings 0.1 to 0.4 foot apart and in the upper half sporadic small chert nodules.	12.5
18. Interbedded quartzite and dolomite; beds up to 3 feet in thickness; quartzite similar to unit 26, but is light gray to medium light gray and contains one bed 2 feet thick of light gray fine-grained clean quartz sandstone near base; dolomite is similar to unit 28 except as follows: one thin bed at base of unit is sandy; one bed in center of unit is light olive gray, very finely crystalline, contains thin siliceous laminae, and weathers light brownish gray; in upper 2 to 3 feet of unit, dolomite occurs as irregular, lenticular masses in the quartzite.	13.0

		Feet
17.	Quartzite, light gray to medium light gray, clean, vitreous, fine-grained; weathers yellowish brown.	4.5
16.	Sandstone, light gray to medium light gray, calcareous, irregularly thin-bedded and flaggy, granular on weathered surface.	3.0
15.	Quartzite, lower part of unit similar to quartzite of unit 17; middle part of unit is very light gray fine-grained sandstone flecked with dark brown; upper part of unit is similar to quartzite of unit 26.	20.0
14.	Dolomite, similar to unit 28; sparsely sandy and poorly bedded in lower 4 to 6 feet; contains 0.4 foot bed of quartzite in the middle; upper 2 feet finely laminated on weathered surface due to thin layers of sand that weather in relief.	14.0
13.	Quartzite, similar to unit 17; thin pitted layers, possibly indicating carbonate rich zones, occur at 0.2 to 0.5 foot intervals on the weathered surface.	5.5
12.	Quartzite, pale yellowish brown, clean, vitreous; contains interbedded dolomite similar to that in unit 28.	12.0
11.	Dolomite, similar to unit 28; with a few chert nodules in the upper 3 feet; abundant fossil fragments 5 feet below top of unit.	11.0
10.	Quartzite, light brownish gray flecked with white, slightly limonitic, medium finely granular.	2.0
9.	Concealed, probable dolomite interval.	10.0
8.	Sandstone, pale yellowish brown, clean, vitreous, quartzitic, medium fine-grained.	4.5
7.	Dolomite, similar to unit 28, but contains interbeds of pale yellowish orange to yellowish orange clean, medium-grained quartz sand-sonte in upper 1.5 feet.	13.0

	Feet
6. Quartzite, pale yellowish brown, clean, vitreous; in two beds, one of which is 0.5 foot thick and the other 3 feet thick; weathers yellowish orange to yellowish gray.	3.5
5. Dolomite, similar to unit 28; contains brown, gray, and almost white thin irregular chert laminae in lower 2.5 feet, and from 6 to 8 feet above base; irregular siliceous crusts and chert nodules occur in upper 5 feet.	22.0
4. Dolomite, similar to unit 28; irregular siliceous encrustations on weathered surface; highly irregular weathered quartzite masses occur in lower part of unit.	8.5
3. Quartzite, pale yellowish brown, clean, vitreous.	2.0
2. Dolomite, similar to unit 28; in beds 0.4 to 0.5 foot thick; sparse siliceous encrustations on weathered surface; base of unit is marked by a 1 foot bed of pale yellowish orange, medium fine-grained, clean, quartz sandstone that weathers yellowish orange.	13.0
Total thickness of the Quadrant formation	327.2

Amsden formation:

1. Dolomite, medium light gray to medium gray, fine- to medium-crystalline or granular; weathers medium light gray to light gray, underlain by heavy red shale float.	4.0

Jurassic System

The marine Jurassic rocks of west-central and southwestern Montana were originally described by Peale (1896, p. 2). He named them Ellis for exposures near Fort Ellis, Montana. The name was later assigned by Weed (1899, p. 2) to marine Jurassic rocks in the Little Belt Mountains. In 1945 Cobban (pp. 1262-1303) proposed raising the Ellis to the status of a group and subdividing the group into three formations--the Sawtooth, the Rierdon, and the Swift, in ascending order.

The nonmarine Morrison formation overlies the Ellis group and is of Upper Jurassic age (Imlay, 1948, pl. 2). The Morrison was named and defined by Eldridge (1896, pp. 60-62) on the basis of exposures along the front of the Rocky Mountains near Morrison, Colorado.

Mr. R. W. Imlay of the U. S. Geological Survey (oral communication) recognized two formations of Jurassic age in the Limestone Hills. The lower of these is the Upper Jurassic Swift sandstone (Imlay, 1948, pl. 4) of the Ellis group; the upper is the Upper Jurassic Morrison formation.

Upper Jurassic series

Swift Sandstone

Swift sandstone unconformably overlies the Phosphoria formation in the Limestone Hills and is 19 feet thick. The formation consists of brownish or yellowish friable calcareous sandstone and locally has a thin basal conglomerate. Characteristically, some beds of sandstone are crowded with pelecypod shells, and it is these beds that are most helpful in recognizing the formation.

Although a major unconformity is present between the Phosphoria formation and the Swift sandstone, no angular discordance is apparent in the Limestone Hills, and, as far as can be determined, the thicknesses of the two formations are constant throughout the mapped area.

The thinness of the Swift sandstone made it impracticable to map as a separate unit, and it was therefore mapped with the Morrison formation as a single unit.

Morrison Formation

The Morrison formation overlies the Swift sandstone with apparent conformity in the Limestone Hills.

It is composed of nonmarine sediments, and, in the Limestone Hills, is the first series of terrestrial beds above the pre-Cambrian rocks. It has a thickness of about 540 feet and consists principally of olive and gray siltstone in the lower part and of similarly colored mudstone in the upper part. Limestone and sandstone beds up to approximately 30 feet in thickness occur throughout the formation, and at many localities three or four individual lenses of sandstone are present at different positions in the upper 50 to 100 feet. These sandstone lenses closely resemble the basal salt-and-pepper sandstone of the overlying Kootenai formation, and it is commonly difficult to determine which sandstone marks the contact.

Detailed stratigraphic section of the
Morrison formation and Swift sandstone,
measured on the north side of Indian Creek (pl. 1),
$NW\frac{1}{4}$ sec. 5, T. 6 N., R. 1 E.,
by M. R. Klepper

	Feet
Kootenai formation:	
45. Sandstone, olive gray, fine-grained.	2.0
44. Sandstone, gray, speckled with darker chert grains; light to medium light gray and medium coarse-grained in lower 9 feet; greenish gray, finer grained, and less conspicuously speckled in the upper 14.6 feet.	23.6
Morrison formation:	
43. Concealed.	11.0
42. Sandstone, gray, speckled, glassy, relatively fine-grained.	1.5
41. Concealed.	2.2
40. Limestone, olive brown, very finely crystalline, sandy or silty, in beds 1 foot thick; weathers brown.	10.1
39. Mudstone, olive and gray, fissile; silty dolomite interbedded; weathers yellowish brown.	23.9
38. Siltstone, light olive gray to yellowish orange, dolomitic, blocky.	10.1
37. Dolomite, gray, dense, silty.	2.9
36. Concealed.	5.8
35. Sandstone, gray, silty, speckled with dark chert fragments.	5.8
34. Sandstone, "salt-and-pepper," medium gray with faint greenish tint; in beds about 0.5 foot thick; lower 2 feet silty and fine-grained, upper 6 feet medium coarse-grained.	8.0
33. Concealed; mostly if not wholly underlain by dark carbonaceous mudstone with one or more lignite layers.	20.4

		Feet
32.	Concealed.	10.2
31.	Mudstone, yellowish orange, punky, blocky; two lignite beds, one 0.5 foot thick and one 0.7 foot thick, in the upper 2 feet of the unit.	5.9
30.	Concealed.	45.4
29.	Mudstone, olive gray and dark greenish gray, hackly to pencilly.	16.1
28.	Concealed.	9.3
27.	Mudstone, olive gray and brownish olive, in part calcareous.	8.1
26.	Concealed.	8.7
25.	Mudstone, olive brown, in beds 0.1 foot thick.	2.5
24.	Concealed.	4.2
23.	Mudstone, olive and dark gray.	13.0
22.	Limestone, siltstone, and sandstone; olive and olive gray silty limestone, limy siltstone, and fine-grained sandstone in beds 0.25 to 0.5 foot thick; in part fissile; abundant dark gray cherty fragments in the upper 6 feet of the unit; weathers orange brown to drab brownish gray.	27.4
21.	Limestone, olive and gray, silty; weathers dark yellowish orange to moderate yellowish brown or lighter.	15.4
20.	Concealed.	9.1
19.	Sandstone, light brownish olive, speckled, fine-grained, calcareous; weathers to medium light gray.	5.1
18.	Quartzite, light olive, dense, calcareous.	1.2
17.	Limestone, dolomite, and siltstone; brownish olive gray, pale yellowish brown, and yellowish brown, silty and dense limestone and dolomite and limy or dolomitic siltstones, with carbonate rocks predominant; siltstones commonly in beds less than 0.02 foot thick, carbonate rocks in beds up to 0.7 foot thick; unit weathers dark yellowish orange, grayish orange, and light olive.	30.8

		Feet
16.	Concealed.	85.8
15.	Siltstone, weathers orange brown.	2.1
14.	Siltstone, punky, calcareous or dolomitic; in part very fine-grained sandstone; unit weathers yellowish brown.	3.4
13.	Sandstone, pale yellowish brown, light olive, and light gray, speckled, fine-grained, somewhat cross-bedded; in beds 0.2 to 1 foot thick; weathers pale yellowish brown.	19.3
12.	Siltstone, orange brown, calcareous, fissile; upper half of unit mostly concealed.	22.7
11.	Siltstone, calcareous, weathers dull yellowish brown.	11.4
10.	Siltstone and limestone; hackly to fissile siltstone interlayered with thicker beds of silty limestone; weathers dark yellowish orange.	14.9
9.	Limestone, brownish olive, silty; weathers brownish.	0.6
8.	Siltstone and limestone, similar to unit 10, but siltstones are calcareous.	11.5
7.	Concealed; underlain, at least in part, by brownish gray, olive, and grayish orange calcareous siltstone that weathers near dark yellowish orange.	17.2
6.	Siltstone, brownish gray, olive, and grayish orange, calcareous, fissile to thin-bedded; weathers near dark yellowish orange.	16.0
5.	Limestone, olive gray, silty, indistinctly bedded; weathers gray to brown.	4.0
	Total thickness of the Morrison formation	523.0

Swift sandstone:

4.	Concealed.	7.0

	Feet
3. Sandstone, brownish gray, speckled, fine-grained; consists of whitish to glassy, subangular to subrounded quartz grains and sparsely scattered chert grains in fine-grained brown-stained sand matrix; unit weathers brownish gray.	11.0
2. Sandstone, moderate dusky yellow, speckled, fine-grained, with subrounded grains, very calcareous, friable.	1.0
Total thickness of the Swift sandstone	19.0

UNCONFORMITY

Phosphoria formation:

1. Chert, dark gray, mottled dull red, brown and white.	1.0

Cretaceous System

Sedimentary rocks of Lower Cretaceous, and Upper (?) Cretaceous age, are present in the Limestone Hills, comprising the Lower Cretaceous Kootenai formation and Cretaceous sedimentary rocks of post-Kootenai age, which in this study have not been subdivided.

Kootenai was first proposed as a formational name by Sir William Dawson in 1885 for exposures of Jurassic and Cretaceous rocks in the Canadian Rocky Mountains. In 1909 Fisher (pp. 28-35) restricted the formation in the vicinity of Great Falls, Montana, applying the name Morrison shale (?) to the lower 130 feet of strata and Kootenai formation to the upper 475 feet. The Kootenai formation of Montana now includes the rocks between the Upper Jurassic Morrison formation and the Cretaceous Thermopolis shale, the lower part of which is Lower Cretaceous. The lower part of the Kootenai formation is equivalent to the Canadian Kootenay formation, and the upper part of the Kootenai is equivalent to the Lower Blairmore formation of Canada (McLearn and Hume, 1927, p. 241).

The rocks overlying the Kootenai formation in the Limestone Hills consist of sandstone, siltstone, and shale of uncertain age. The rocks may be equivalent to part of the Thermopolis shale (Lupton, 1915, p. 168; Reeside, 1944) or to the lower part of the Colorado group (Hayden, 1876, p. 45) as redefined by White (1878, pp. 21-22, 30).

Lower Cretaceous series

Kootenai Formation

The Kootenai formation in the Limestone Hills is 529 feet thick at locality 3 (pl. 1) and consists of sandstone, mudstone, shale, and limestone. Sandstone is predominant in the lower part of the formation; shale, mudstone, and limestone are predominant in the upper part.

The base of the Kootenai is marked by a thick, fairly resistant quartzitic "salt-and-pepper" sandstone that closely resembles the lenticular sandstones of the upper part of the Morrison formation. The uppermost part of the Kootenai is characterized by a conspicuous gray limestone unit crowded with gastropods.

Upper (?) Cretaceous series

Sedimentary Rocks, Undivided

The Kootenai formation in the Limestone Hills is overlain, with apparent conformity, by about 125 feet of dark gray marine siltstone and shale; the contact is placed about 10 feet above the gastropod-bearing limestone of the Kootenai formation at the base of a light-colored quartzitic sandstone bed 5 to 15 feet thick. The post-Kootenai rocks may be equivalent to the Lower Cretaceous part of the Thermopolis shale (Reeside, 1944), or to the lower part of the Upper Cretaceous Colorado group (White, 1878, pp. 21-22, 30). In this paper they are assigned tentatively to the Upper Cretaceous.

Detailed stratigraphic section of the Kootenai formation, measured at section locality 3 (pl. 1), SW$\frac{1}{4}$ sec. 5, T. 6 N., R. 1 E.

Sedimentary rocks of Upper (?) Cretaceous age; undivided:	Feet
67. Shale, medium dark gray, fissile, papery to thinly platy; in part contains very finely divided mica.	40.9
66. Siltstone, dark gray, hard, blocky; alternating beds of dark gray and very dark gray, fissile, papery shale on lower 20.5 feet of unit and two moderately thick beds of similar shale in the upper 28.6 feet; weathers yellowish gray; fossil collection R 416 (field number) from 3.3 feet above base of the unit.	49.1
65. Concealed, probably underlain by olive and gray, compact, blocky siltstone.	27.3
64. Siltstone, dark gray, compact, blocky.	6.0
63. Sandstone, light olive gray to yellowish brown, clean, quartzitic; weathers pale yellowish brown.	2.5
Total measured thickness of Sedimentary rocks of Upper (?) Cretaceous age	125.8
Kootenai formation:	
62. Siltstone, dark gray, coarse-grained, compact, blocky; very calcareous in lower 2 feet of unit.	5.5
61. Concealed; shale interval.	4.0
60. Limestone, dark gray, dense to finely crystalline; lumpy weathering.	2.0
59. Concealed.	12.0
58. Limestone, medium dark gray, irregularly bedded; weathers medium gray to medium light gray.	2.5
57. Siltstone, micaceous; contains 0.5 foot platy gray limestone bed in middle of unit.	3.0
56. Limestone, gray, platy.	1.0

	Feet
55. Sill, decomposed; contains abundant biotite phenocrysts.	2.0
54. Limestone, dark gray, very finely crystalline; contains scattered pebbles and chips of limestone similar to that in unit 53; weathers light gray to light olive gray; fossil collection R 415 (field number) from unit.	4.8
53. Limestone, medium dark gray, granular, fetid; fossil gastropods abundant; weathers medium gray to dark yellowish brown.	2.4
52. Limestone, medium gray to medium dark gray, very fine-tomedium-crystalline; contains a a few gastropod-rich layers; weathers medium light gray.	5.7
51. Limestone, similar to unit 53, but only slightly fetid.	1.4
50. Concealed.	10.6
49. Shale, interbedded grayish red to grayish purple and greenish gray to light olive gray; grayish red predominant in lower 48 feet, greenish gray predominant in upper 23.6 feet; fissile to thinly platy; contains irregular thin, lenticular and ovoidal, dense limestone concretions from 4.3 to 14 feet above base; 0.2-foot brown-weathering, dense, concretionary limestone bed occurs 48 feet above base.	71.6
48. Shale, pale red to grayish red, with subordinate light olive gray to greenish gray interbeds; fissile to chippy, subhackly; zone of irregular, ovoidal to spherical, brown-weathering limestone concretions occurs from 12.1 to 13.3 feet above base of the unit.	16.9
47. Mudstone, light olive gray to olive gray, with subordinate grayish red interbeds, platy to subfissile.	3.0
46. Limestone, pale purple to pale reddish purple, locally with pale green tint, very finely crystalline, subconchoidal fracture; weathers dark yellowish brown.	0.6

		Feet
45.	Mudstone, light olive gray to olive gray, with grayish red interbeds in upper 6 feet, platy to subfissile; thin zone of limestone concretions, similar to those of unit 49, occurs 20.6 feet above base of the unit.	27.3
44.	Concealed.	20.2
43.	Mudstone, light olive gray, thinly platy.	4.0
42.	Limestone, dark gray, dense, contains scattered small calcite crystals; very fossiliferous; fossil collection R 414 (field number) from unit.	0.5
41.	Shale, yellowish gray to light olive gray, fissile to chippy.	3.0
40.	Shale, dusky blue to grayish purple, fissile to finely chippy.	3.0
39.	Concealed.	3.0
38.	Limestone, pale purple to grayish red purple, very finely crystalline; weathers dusky yellowish brown.	1.0
37.	Shale, grayish red, with grayish olive interbeds in lower 6 feet, fissile; limestone concretions similar to those in unit 49 abundant in upper 1 foot.	16.0
36.	Shale, grayish olive, fissile, micaceous; contains thin, lenticular and flattened, similarly colored dense limestone concretions in the upper 4 feet.	15.0
35.	Mudstone, light olive gray to greenish gray, fissile, pencilly, and chippy; contains sparsely disseminated light gray dense limestone concretions up to 2 inches in diameter; upper 1 foot is principally medium gray concretionary limestone that weathers to irregular rounded pieces up to 8 inches in diameter.	16.0
34.	Mudstone, light greenish gray, very thin- and irregularly bedded; weathers very light gray.	6.0
33.	Mudstone, greenish gray and yellow gray, fissile to blocky; pencilly in lower 5 feet; weathers yellowish orange.	10.0

	Feet
32. Shale, grayish purple to very dusky purple, very fissile; conspicuous rounded sublithographic limestone concretions up to 5 inches in diameter occur in zones 2 feet thick near the top and bottom of the unit.	16.0
31. Concealed; red shale float.	19.0
30. Siltstone, yellowish gray to grayish yellow in lower half and pale red to grayish red in upper half of unit; sparse limestone concretions throughout.	9.0
29. Sandstone, white, clean, in beds 0.4 foot thick; grayish yellow, in part irregularly rippled, mudstone interbedded.	6.0
28. Sandstone, pale yellowish brown, limonitic; contains subordinate rounded black chert grains; medium-grained; in beds 0.4 to 1 foot thick.	17.0
27. Sandstone, yellowish gray, fine-grained, compact, in beds 0.5 to 0.7 foot thick; contains interbeds of yellowish orange, grayish, and grayish red, platy, fissile, irregularly lumpy mudstone.	9.1
26. Concealed; float is red mudstone.	8.4
25. Mudstone, pale red to grayish red, poorly fissile, thinly platy, irregularly lumpy.	2.1
24. Sandstone, medium-grained, limonitic.	0.7
23. Mudstone, similar to unit 25.	13.3
22. Mudstone, yellowish orange, platy to chippy.	1.4
21. Concealed.	4.0
20. Conglomerate, fine-grained sandstone matrix with pebbles of yellowish siltstone and light gray limestone.	2.0
19. Concealed.	6.0
18. Sandstone, pale reddish brown, very fine-grained.	2.0

		Feet
17.	Sandstone, medium gray, "salt-and-pepper," medium-grained, compact, quartzitic, in beds 0.25 to 0.75 foot thick.	10.0
16.	Mudstone, interbedded pale red and grayish yellow, chippy to lumpy; 0.3-foot bed of reddish brown fine-grained blocky sandstone at base of unit.	13.0
15.	Sandstone, pale reddish brown, very fine-grained, blocky; grayish yellow, fissile, lumpy mudstone interbedded.	4.0
14.	Conglomerate, subrounded gray limestone and orange siltstone fragments up to 0.25 inch in diameter in a matrix of sand and mud.	2.0
13.	Mudstone, interbedded yellowish gray and pale red, fissile to thinly platy and lumpy.	15.0
12.	Concealed.	2.0
11.	Sandstone, pale yellowish brown, slightly calcareous, very fine-grained; contains sparsely disseminated black chert pebbles.	1.0
10.	Concealed.	7.0
9.	Limestone, pale yellowish brown, dense, sublithographic, intimately admixed; yellowish gray mudstone, contains edgewise pebbly zone in upper 0.5 foot.	7.0
8.	Mudstone, olive gray, somewhat hackly; contains small limestone chips or flattened concretions.	9.0
7.	Concealed.	9.0
6.	Mudstone, similar to unit 8, but contains small concretions of light olive gray, dense limestone in upper part.	17.0
5.	Mudstone, dark gray, platy; weathers light gray.	1.0
4.	Concealed.	8.0

	Feet
3. Sandstone, pale yellowish brown to light gray, medium-grained, homogeneous, quartzitic, very indistinctly bedded to massive; weathers to large, irregular blocks up to 6 feet in diameter.	36.0
Total thickness of the Kootenai formation (excluding sills)	529.0
Morrison formation:	
2. Concealed.	35.0
1. Sandstone, light olive gray, medium fine- to medium-grained, limonitic; in beds less than 1 foot thick, which are cross-bedded on a small scale.	31.0

Tertiary System

Tertiary strata in the Limestone Hills consist of slightly consolidated, very fine textured volcanic ash underlain by conglomerate loosely cemented with calcite. The conglomerate contains pebbles from most of the formations exposed in the area and overlies the older formations with strong, angular discordance.

The Tertiary strata present in the area are probably equivalent to lower Oligocene beds in nearby areas described by Pardee (1926, pp. 22-29).

Quaternary System

The only Quaternary deposit recognized in the Limestone Hills is the flood plain alluvium of Crow Creek and its tributaries. The alluvium consists of boulders, cobbles, and finer sediments transported mainly from the Elkhorn Mountains to the west.

IGNEOUS ROCKS

All of the igneous rocks in the Limestone Hills are intrusive, but extrusive rocks occur a short distance west of the area. Most of the igneous rocks in the area have the form of sills, but two small stocks and one narrow dike were recognized. One of the stocks is in secs. 3 and 4, T. 6 N., R. 1 E.; the other is in sec. 20, T. 6 N., R. 1 E. These stocks are referred to in this paper as the northeast and southwest stocks respectively.

Sills

Sills of igneous rock are distributed throughout the Limestone Hills; they have, with few exceptions, intruded the least resistant sedimentary rocks, principally the Three Forks shale, the Kootenai formation, and the sedimentary rocks of Upper(?) Cretaceous age. The thin but persistent sill in the Kootenai formation has intruded the gastropod-bearing limestone, and an unmapped sill of very small areal extent occurs in the upper part of the Meagher limestone in sec. 28, T. 6 N., R. 1 E. A third body of igneous rock, of indeterminate but probable sill-like form, has been emplaced in the Lodgepole limestone in the SW$\frac{1}{4}$ sec. 27, T. 7 N., R. 1 E. This body appears to be discordant along its southwestern margin and concordant elsewhere; it is best classified as a sill-like pluton. Three remnants of Lodgepole limestone are present in the pluton, and all have the same general trend as the surrounding sedimentary rock. All other sills are in shaly or silty beds.

Individual sills extend from about 500 feet to 4 miles along the strike, and, with one exception, range in thickness from about 1 to 50 feet; the exceptional sill in the Three Forks shale in the central part of the area has a maximum thickness of about 2,000 feet.

Megascopically the rocks forming the sills, the sill-like pluton, and the one small dike are somewhat similar and appear to have a dioritic composition. They are gray or grayish olive and range from finely to coarsely crystalline, although the degree of crystallinity of the rock in a single body remains about the same throughout that body.

Microscopic examination of thin sections from the major sills indicates, however, that the rocks vary considerably in composition. The rock in the thick central sill is a hornblende granodiorite composed of andesine, hornblende, quartz, orthoclase, and a minor amount of epidote and magnetite. The approximate mineral composition of the rock is as follows: andesine, 60 percent; hornblende, 10 percent; quartz, 20 percent; and orthoclase, 10 percent. The texture of the rock is normally granitic, but, at the northern part of the sill, a microcrystalline groundmass of quartz and potash feldspar is irregularly distributed through the granitic rock.

The sill in the gastropod-bearing limestone of the Kootenai formation consists of granodiorite in the southern part and diorite((?) in the northern part. The granodiorite has a composition similar to that of the central sill but is porphyritic with a finely crystalline groundmass. The diorite (?) is fine-grained and porphyritic and consists of approximately 20 percent plagioclase phenocrysts in a groundmass of plagioclase intergrown with hornblende, and a small amount of quartz and orthoclase.

The sill which intrudes the shales of Upper (?) Cretaceous age is porphyritic andesite consisting of about 40 percent plagioclase phenocrysts, probably andesine, and about 60 percent groundmass. The groundmass is an irregular intergrowth of minute plagioclase laths, chlorite, edidote, quartz, and orthoclase (?). Both quartz and orthoclase (?) are present only in small amounts, together forming less than 15 percent of the total volume of the rock.

Northeast Stock

The northeast stock is composed of a light gray, porphyritic rock. The rock consists of about 30 percent plagioclase, between oligoclase and andesine, and 7 percent hornblende as phenocrysts; the remaining 63 percent is a groundmass of very finely crystalline quartz and orthoclase in approximately equal amounts. The overall composition of the rock is about that of quartz monzonite; the phenocrysts suggest diorite, and the groundmass suggests granite. The rock might most appropriately be called porphyritic quartz latite.

Southwest Stock

The southwest stock is composed of three rock types, one of which occurs as a thin marginal zone around the main mass of a second type, and the third of which forms two small tongues from the southern part of the stock.

The main mass of the stock is a medium-dark gray porphyritic rock that consists of about 5 percent olivine and 30 percent pyroxene, occurring mainly as phenocrysts, and 65 percent fine-grained groundmass of which plagioclase (oligoclase ? or andesine ?) forms about 50 percent; potash feldspar (probably either sanidine or anorthoclase) about 13 percent; quartz about 2 percent; and biotite and magnetite together about 1 percent. The rock is too finely crystalline to be a typical gabbro and too coarsely crystalline to be a typical basalt; it might best be referred to as porphyritic sanidine or anorthoclase microgabbro.

The thin marginal zone surrounding the body of microgabbro is a light gray to medium gray, medium- to finely crystalline rock composed of plagioclase, orthoclase, quartz, and subordinate chlorite, probably a replacement of biotite. Plagioclase (probably andesine) forms about 10 percent of the total volume, orthoclase about 50 percent, quartz about 10 percent, a micropegmatitic intergrowth of quartz and orthoclase about 20 percent, and chlorite about 10 percent. The rock is a fine-grained chlorite granite.

The two small tongues from the stock are composed of medium dark gray porphyritic rock that consists of pyroxene, biotite (and chlorite), plagioclase, orthoclase, quartz, and minor amounts of magnetite, epidote, and apatite. Phenocrysts, predominantly pyroxene, form about 20 percent of the rock. The fine-grained groundmass consists of about 50 percent plagioclase (probably calcic andesine), 18 percent biotite and chlorite, 6 percent orthoclase, and 4 percent quartz. The rock is a porphyritic microdiorite.

Age of Intrusions

The occurrence of dioritic sills and the dike in the post-Kootenai sedimentary rocks, of Upper (?) Cretaceous age, the presence of Oligocene (?) volcanic ash and underlying conglomerate resting unconformably upon eroded granodiorite sills, and the absence of any structural deformation in the microgabbro and quartz latite stocks indicate that the igneous rocks of the Limestone Hills are post-Lower Cretaceous and pre-Oligocene (?) in age. The igneous rocks cannot be more closely dated in the mapped area, and no evidence concerning the age relationship of one igneous rock type to another was found.

The igneous rocks in the Limestone Hills appear to be similar in both composition and mode of occurrence to those in the Marysville mining district northwest of Helena described by Barrell (1907, pp. 12-15, 40-56). If relationships between the igneous rocks in the two areas are analogous, the dioritic rocks are probably late Cretaceous or early Tertiary in age and the microgabbro is probably of early Tertiary age; the quartz latite may possibly be related to the Boulder batholith of Eocene (?) age.

CONTACT METAMORPHISM

Wherever igneous rocks have intruded sedimentary rocks in the Limestone Hills, the latter have been metamorphosed. Generally, the metamorphism has been slight, consisting only of a hardening with no detectable change in mineral composition. More severe contact metamorphic effects were observed in the Three Forks shale adjacent to the large central sill, in the Limestone of the Kootenai formation adjacent to the narrow granodiorite sill, and in the Park shale and Meagher limestone adjacent to the quartz latite stock. Characteristic features of the metamorphism adjacent to these intrusive rocks are described below.

Metamorphism Adjacent to the Central Sill

Conspicuous contact metamorphic effects were observed only near the upper contact of the central granodiorite sill. The lower part of the Three Forks shale and the underlying formations are not noticeably affected. Commonly, strata overlying the sill are somewhat altered. The upper calcareous siltstone of the Three Forks shale, where present above the sill, characteristically is altered to a white, dense, blocky hornfels that is conspicuous both in outcrop and as float. The Lodgepole limestone is only slightly affected; locally, its bluish tint becomes a slightly darker gray. Although recrystallization is not intense, recognizable fossils are uncommon where the Lodgepole has been altered. Locally, the basal part of the Mission Canyon limestone is bleached from gray to almost white and is recrystallized to an extremely coarsely crystalline marble. Individual crystals in recrystallized Mission Canyon limestone are as much as 0.5 inch in diameter.

Metamorphism Adjacent to the Sill in the Kootenai Formation

The granodiorite sill in the Kootenai formation has altered and recrystallized the adjacent limestone. A zone of complete recrystallization, which ranges in thickness from less than 1 inch to about 6 inches, immediately adjoins the sill. In this zone, the limestone has been recrystallized to produce fibrous calcite that has a satiny luster on the weathered surface. The individual fibers or columns have their long dimension normal to the granodiorite-limestone contact. The rest of the gastropod limestone has commonly been recrystallized to the extent that only vestiges of the gastropods remain. Rocks above and beneath the limestone have not been affected by the sill.

Metamorphism Adjacent to the Quartz Latite Stock

The most intensive contact metamorphism in the Limestone Hills took place around the quartz latite stock in secs. 3 and 4, T. 6 N., R. 1 E. The Park shale, into which the stock was intruded, was altered to a dense, blocky, dark gray hornfels as far as 600 feet from the margin of the stock. In the upper part of the Meagher limestone to the east, the normally yellowish mottling was changed to a brownish or grayish color. The lower part of the Pilgrim limestone to the west was similarly affected, although not so extensively.

STRUCTURAL GEOLOGY

The Limestone Hills constitute part of the western limb of a broad, north-trending anticline, the axis of which probably lies near the present course of the Missouri River about 5 miles east of the area. The strata in the southern and central parts of the area commonly dip steeply to the west, although locally they have been overturned and dip steeply to the east. Overturning is localized adjacent to some of the faults, where it is apparently due to drag, and along the western margin of the central sill, where it is probably a result of the force of intrusion. In the northernmost and northwestern parts of the area the westward dip is relatively gentle.

The most prominent structural features in the map area are the many northwest-trending normal faults. Two faults that parallel the strike of the beds occur in the area--one in secs. 21 and 28, T. 6 N., R. 1 E., and one in secs. 17 and 20, T. 6 N., R. 1 E. These faults are referred to in this paper as the eastern and western strike faults. Minor folds were recognized at two localities within the area--one in sec. 29, T. 6 N., R. 1 E., and the other in secs. 32 and 33, T. 7 N., R. 1 E.

Folds

The most prominent minor folds not definitely related to faults are at the southwestern margin of the Limestone Hills. At this locality, the Mission Canyon, Amsden, and Quadrant formations have been tightly folded into an anticline and a syncline, both of which plunge steeply to the south. The trends of the axes of these folds closely parallel the probable trend of the axis of the major anticline, and their plunge is in the same direction as that of the major anticline.

In the northwestern part of the Limestone Hills, the Amsden formation has been flexed into three minor folds. These folds undoubtedly also extend into the Mission Canyon limestone, but in this massive unit they cannot be traced.

Normal Faults

All of the faults in the Limestone Hills are high-angle normal faults. They were observed cutting rocks of all ages in the area except Tertiary, but were most common in rocks of Cambrian and Devonian age.

The dominant normal faults in the area trend N. 60° to 80° W., making an angle of about 70° with the strike of the beds. At the northern end of the area one fault trends N. 35° W. but has the same angular relationship to the strike of the beds as the other normal faults. Some of the smaller faults trend N. 60° to 80° E., particularly in the southern part of the area.

The fault surfaces of most of the normal faults dip steeply to the south, probably at angles of 80° to 85°. A few faults dip steeply to the north.

The stratigraphic displacement of the normal faults is commonly less than 150 feet, but two faults have a considerably greater displacement. One of these is in secs. 27 and 34, T. 7 N., R. 1 E.; the other is the conspicuous fault in secs. 8, 15, and 16, T. 6 N., R. 1 E., subsequently referred to in this paper as the Indian Creek fault.

The northernmost normal fault dips steeply to the south and has a maximum stratigraphic displacement of about 1,400 feet, placing the Flathead quartzite in fault contact with the Pilgrim limestone.

The Indian Creek fault, which also dips steeply to the south, has a maximum stratigraphic displacement of about 1,000 feet. It continues with the same general trend for a considerable distance west of the Limestone Hills and controls a part of the channel of Indian Creek. To the east, the fault extends across the central sill and appears to horsetail out in the massive Devonian and Cambrian limestones and dolomites, where it loses its identity as a single fault and branches into five fairly distinct normal faults, at least one of which again branches.

The manner in which the Indian Creek fault horsetails illustrates the typical reactions to deforming stresses of the Flathead, Wolsey, Meagher, and Park formations. The Flathead quartzite typically breaks when subjected to differential stress. The Wolsey and Park shales commonly are conspicuously thinned where any major fault cuts them, and are compensatingly thickened elsewhere along the strike. The Meagher limestone apparently yields by plastic flow when subjected to deforming stresses, and in this area has been completely offset by only one fault. Many faults that cut one contact of the formation are reflected by a minor roll on the opposite contact, and by a thinning of the formation. The deformative forces appear to have been dissipated principally by flowage of the limestone to areas of less stress, and the Meagher was thereby correspondingly thinned and thickened.

Strike Faults

The eastern strike fault cuts strata of Cambrian and Devonian age, but has been observed mainly in the Upper Cambrian Pilgrim limestone where it has resulted in repetition of all units of the Pilgrim but the basal mottled and banded limestone. It is a normal fault that dips to the west, probably at an angle of less than 50°. The fault dies out in a small anticline in the Meagher limestone on the north, and is dissipated in the thick Jefferson dolomite on the south. It is probably related in origin to the intrusion of the thick central sill.

The western strike fault cuts the Mission Canyon, Amsden, Quadrant, and Phosphoria formations. The entire Quadrant and

Phosphoria formations, most of the Amsden formation, and a small part of the upper part of the Mission Canyon limestone are repeated above the fault surface. The fault is normal and dips westward, probably at an angle no greater than 65°. Northward it passes into a minor anticline in the Mission Canyon limestone and southward it dies out in the shales of the Morrison formation. This fault may have been caused by the intrusion of the gabbroic stock, with which it is closely associated; if so, the stock was probably very viscous when intruded.

GEOLOGIC HISTORY

The absence of any observable angularity between the rocks of the Belt series and the Flathead quartzite suggests that the region was but slightly upwarped after deposition of pre-Cambrian sediments and remained close to base level until Middle Cambrian time. The lithologic sequence of the oldest Cambrian sediments, specifically quartzite (Flathead), shale (Wolsey), and limestone (Meagher), suggests that the sea in which they were deposited was transgressive. Similarly, the sequences of lithologies in the Park shale, Pilgrim limestone, and lower unit of the Dry Creek (?) shale suggest fluctuations of the sea subsequent to deposition of the Meagher limestone.

No angular or erosional unconformity is evident between the upper and lower units of the Dry Creek (?) shale; therefore, the Limestone Hills must have remained close to sea level, where erosion would be slight during Ordovician, Silurian, and part of Devonian time.

The silty carbonate rocks of the upper (Devonian) unit of the Dry Creek (?) shale and the Jefferson dolomite were deposited in a sea that invaded the area during later Devonian time and that may have remained until the end of the Carboniferous. The sea probably receded slightly during the deposition of the fine clastics of the Three Forks shale, but again advanced and was relatively stable while the Madison limestone was deposited. The Limestone Hills were probably submerged during all of Mississippian time, for upper Mississippian fossils are present in the upper part of the Mission Canyon limestone. The fine clastic sediments of the Amsden formation suggest, however, that the sea had begun to recede somewhat from the Limestone Hills area before the end of the Mississippian. The alternating clastic and carbonate rocks of the Quadrant formation indicate repeated oscillations of a highly unstable sea during Pennsylvanian time. No break is evident between the Quadrant and Phosphoria formations, and in the vicinity of the Limestone Hills the Permian Phosphoria sea was probably a continuation of the Pennsylvania sea. The Phosphoria sea withdrew from the area at the end of the Permian, and the Limestone Hills were above sea level during Triassic and part of Jurassic time.

The Phosphoria formation in this area is very thin as compared with sections elsewhere in southwestern Montana. The constant thickness and lithology of the formation suggest that no appreciable amount of material was removed by erosion during the Triassic and the Lower and Middle Jurassic. The writer considers it more probable that the Limestone Hills were near the margin of the Phosphoria sea and received sediments only sporadically during Permian time.

The area was again submerged in Upper Jurassic time and the marine Swift sandstone was deposited. As the Swift sandstone is uniformly thin throughout the area, either deposition must have been slow and long continued or the submergence must have lasted only a relatively short time, during which deposition was fairly rapid. The nature of the sediments favors a short, rapid deposition.

The sedimentary rocks of the Morrison and Kootenai formations indicate that nonmarine conditions existed in the Limestone Hills during the late Jurassic and early Cretaceous. Similarly, the dark gray shales and siltstones of post-Kootenai age suggest that the area was again submerged after deposition of the Kootenai formation.

It is evident from the apparent conformity of contacts between the pre-Cambrian, Paleozoic, and Mesozoic formations that no strong structural deformation took place in the Limestone Hills prior to late Cretaceous. The uplifts must all have been broad and gentle, and the region probably was never much above base level during intervals of nondeposition in Paleozoic and most of Mesozoic time.

The rocks in the Limestone Hills were deformed after deposition of the Upper (?) Cretaceous sediments and before deposition of the Oligocene (?) conglomerate and ash beds, for the Oligocene (?) rocks rest with angular discordance upon steeply dipping Cretaceous rocks. Although the deformation cannot be dated more closely, it undoubtedly took place during the Laramide revolution in late Cretaceous and early Tertiary time. The igneous intrusions were probably related, at least in part, to this deformation and, if their relationships are analogous to those in the Marysville district (Barrell, 1907, pp. 12-15), the intrusion of granodiorite probably accompanied the deformation and was followed in early Tertiary time by the intrusion of gabbro and quartz latite.

The distribution of the Oligocene (?) ash and conglomerate beds indicates that they were deposited upon a surface not greatly different in configuration from the present-day surface.

ECONOMIC GEOLOGY

The principal known mineral resources of the Limestone Hills are building stone and quartz sandstone. Despite the numerous igneous intrusives in and adjacent to rocks usually considered receptive to replacement by metallic minerals, no metallic deposits of economic value have been found, although a number of minor occurrences have been prospected.

Metalliferous Deposits

Metallic minerals have been deposited in rocks of the Belt series, in the Meagher limestone, and in the Pilgrim limestone. The upper light gray dolomite unit of the Pilgrim appears to be most receptive to replacement by metallic minerals. Silicified zones are common along the ridge formed by this dolomite, and most of them have been prospected by small pits and other workings. The most extensive workings, located near the mutual corner of secs. 3, 4, 9, and 10, T. 6 N., R. 1 E., consist of three shafts from 50 to 100 feet deep which are probably connected by levels underground. These workings appear to explore a shear zone that trends N. 70° E. and that contains some pyrite and chalcopyrite.

The contact metamorphic aureole of the quartz latite stock has been most intensively prospected. Most of the prospects in this area explore silicified limestone; metallic minerals were observed at only three of the prospects. Two of these, located near the eastern boundary of sec. 4, T. 6 N., R. 1 E., are characterized by small amounts of malachite in shale and limestone. The third, in the northwest quarter of sec. 3, T. 6 N., R. 1 E., is in a small deposit of marcasite in limestone at the base of the Meagher.

The only other prospect in which metallic minerals were observed is in the Belt series in sec. 27, T. 6 N., R. 1 E., on the eastern boundary of the area. The prospect is on a quartz vein that trends about N. 85° W., is from 1.5 to 3 feet thick, and contains sparsely disseminated malachite. The principal working is a caved vertical shaft on the vein. Other smaller pits and shafts explore the same vein eastward for a distance of about 200 feet.

Prospect pits are common in the Flathead quartzite, but no metallic minerals were observed at any of these pits.

Building Stone

Most of the limestone and dolomite in the Limestone Hills is probably suitable structurally for building stone, but because of the undesirable dark color of much of the rock and the limited local market, little has been used. The mottled and banded limestone of the upper part of the Meagher is apparently both structurally suitable and attractive, for it was formerly quarried as a building stone. The quarry in sec. 4, T. 5 N., R. 1 E., was opened by the Vermont Marble Company and was operated by this company between 1928 and 1930 and for about three months in 1937. Since that time the quarry has been idle.

The quarry opening is now 35 feet long parallel to the strike of the beds, 47 feet wide normal to the strike, and 72 feet deep. Eleven floors were either totally or partly quarried, but the upper five floors, or about 35 vertical feet of rock, were not marketable because of imperfections and unsoundness induced by weathering.

The Vermont Marble Company has kindly permitted the release of the following information concerning production from the quarry: in 1929, 6,290 cubic feet of rock was quarried and 3,190 cubic feet, or 51 percent, was saved as marketable blocks; during 1937, 14,307 cubic feet of rock was quarried and 2,199 cubic feet, or 15 percent, was saved. The low percentage saved in 1937 was due to shattering of the fifth and sixth floors when the upper four floors were blasted off.

The limestone was sold under the trade name of Montana Black and Gold marble, and was used primarily as a base under other marble die, although some was used for decorative purposes.

Quartz Sandstone

The Flathead quartzite is a pure quartz sandstone, and as such is of local economic value. During part of 1948 and 1949 it was quarried at one locality in the Limestone Hills--in the northwestern corner of sec. 27, T. 6 N., R. 1 E. The quarry (pl. 3), 3/ operated by Mr. Russell Stewart of Townsend, Montana, was opened in 1948. Up to the end of 1949, 6,200 tons of sandstone, averaging 88 percent silica, had been produced. The sandstone is trucked to Trident, Montana, where it is used by the Ideal Cement Company in the manufacture of cement.

3/ The photograph of the Stewart quarry and the production figures given above are published by permission of Mr. Russell Stewart.

BIBLIOGRAPHY

Barrell, Joseph, Geology of the Marysville mining district: U. S. Geol. Survey Prof. Paper 57, 1907.

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

Blackwelder, E., New geological formations in western Wyoming: Washington Acad. Sci. Jour., vol. 8, 1918.

Cobban, W. A., Marine Jurassic formations of the Sweetgrass Arch, Montana: Am. Assoc. Petrol. Geol. Bull., vol. 29, no. 9, 1945.

Collier, A. J., and Cathcart, S. H., Possibility of finding oil in laccolithic domes south of the Little Rocky Mountains, Montana: U. S. Geol. Survey Bull. 736, 1922.

Condit, D. D., Relations of late Paleozoic and early Mesozoic formations of southwestern Montana and adjacent parts of Wyoming: U. S. Geol. Survey Prof. Paper 120-F, 1918.

Condit, D. D., Finch, E. H., and Pardee, J. T., Phosphate rock in the Three Forks-Yellowstone Park region, Montana: U. S. Geol. Survey Bull. 795, 1928.

Corry, A. V., Some gold deposits of Broadwater, Beaverhead, Phillips, and Fergus Counties, Montana: Mont. Bur. Mines and Geol. Mem. 10, 1933.

Darton, N. H., Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, 1904.

Deiss, C. F., Revision of type Cambrian formations and sections of Montana and Yellowstone National Park: Geol. Soc. America Bull., vol. 47, no. 8, 1936.

Eldridge, G. H., Geology of Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, 1896.

Fisher, C. A., Geology of the Great Falls coal field, Montana: U. S. Geol. Survey Bull. 356, 1909.

Hayden, F. V., Geological report of the exploration of the Yellowstone and Missouri Rivers: Govt. Printing Office, 1869.

Hayden, F. V., U. S. Geol. and Geog. Survey Terr. 8th Ann. Rept., 1876.

Imlay, R. W., Characteristic marine Jurassic fossils from the western interior of the United States: U. S. Geol. Survey Prof. Paper 214-B, 1948.

Lupton, C. T., Oil and gas near Basin, Big Horn County, Wyoming: U. S. Geol. Survey Bull. 621, 1915.

Mansfield, G. R., and Richards, R. W., The Bannock overthrust, a major fault in southeastern Idaho and northeastern Utah: Jour. Geol., vol. 20, 1912.

McLearn, F. H., and Hume, G. S., The stratigraphy and oil prospects of Alberta, Canada: Am. Assoc. Petrol. Geol. Bull., vol. 11, no. 3, 1927.

Pardee, J. T., The geology and ground water resources of the Townsend Valley, Montana: U. S. Geol. Survey Water-Supply Paper 539, 1926.

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

Peale, A. C., U. S. Geol. Survey Geol. Atlas, Three Forks folio (no. 24), 1896.

Reeside, J. B., Jr., Maps showing thickness and general character of the Cretaceous deposits in the western interior of the United States: U. S. Geol. Survey Oil and Gas Investigation Prelim. Map 10, 1944.

Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, 1913.

Scott, H. W., Some Carboniferous stratigraphy in Montana and northwestern Wyoming: Jour. Geol., vol. 43, no. 8, part II, 1935.

Sloss, L. L., Gardner, L. S., Hendricks, T. A., Hadley, H. D., and Rogers, C. P., Jr., Stratigraphic sections of upper Paleozoic and Mesozoic rocks in south-central Montana: Montana Bur. of Mines and Geol. Mem. 24, 1946.

Sloss, L. L., and Laird, W. M., Devonian system in central and northwest Montana: Am. Assoc. Petrol. Geol. Bull., vol. 31, no. 8, 1947.

Walcott, C. D., Pre-Cambrian fossiliferous formations: Geol. Soc. America Bull., vol. 10, 1899.

Weed, W. H., U. S. Geol. Survey Geol. Atlas, Yellowstone Park folio (no. 30), 1896.

Weed, W. H., U. S. Geol. Survey Geol. Atlas, Fort Benton folio (no. 55), 1899.

Weed, W. H., Geology of the Little Belt Mountains, Montana: U. S. Geol. Survey 20th. Ann. Rept., part 3, 1900.

White, W. H., Report on the geology of a portion of northwestern Colorado: U. S. Geol. and Geog. Survey Terr. 10th Ann. Rept., 1878.