5-1971

Geology Of The Hogback Mountain Area, Northern Big Belt Mountains, Montana.

William L. Shaffer

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of The University of New Mexico in partial fulfillment of the requirements for the degree of

Master of Science

GEOLOGY OF THE HOGBACK MOUNTAIN AREA,
Title NORTHERN BIG BELT MOUNTAINS, MONTANA

William L. Shaffer
Candidate

Geology
Department

David T. Benedetti *Dean*

May 13, 1971 *Date*

Committee

Lee A. Woodward *Chairman*

Sherman A. Wengerd

Albert M. Kudo

GEOLOGY OF THE HOGBACK MOUNTAIN AREA, NORTHERN BIG BELT MOUNTAINS, MONTANA

BY

William Leroy Shaffer
B.G.E., University of Minnesota, 1964

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Geology
in the Graduate School of
The University of New Mexico
Albuquerque, New Mexico
June, 1971

GEOLOGY OF THE HOGBACK MOUNTAIN AREA, NORTHERN BIG BELT MOUNTAINS, MONTANA

BY

William Leroy Shaffer

ABSTRACT OF THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Geology
in the Graduate School of
The University of New Mexico
Albuquerque, New Mexico
June, 1971

ABSTRACT

The Hogback Mountain area is located in the northern part of the Big Belt Mountains, twenty miles northeast of Helena, Montana.

Sedimentary rocks range in age from Precambrian to Recent, and have an aggregate thickness of about 16,500 feet. The oldest stratified rocks are two conformable formations of the Precambrian Belt Series; the Newland Formation (oldest) and the Greyson Shale. These rocks have an aggregate thickness of about 10,700 feet.

Rocks of the Belt Series are unconformably overlain by about 1,200 feet of strata of Middle and Late Cambrian age separated into five conformable formations: the Flathead Sandstone (oldest), Wolsey Shale, Meagher Limestone, Park Shale, and Pilgrim Limestone (youngest).

The Pilgrim Limestone is disconformably overlain by the Jefferson Dolomite, 600-700 feet thick, of Late Devonian age, and the Three Forks Formation, 150-250 feet thick, of Late Devonian and Early Mississippian age.

Conformably above the Three Forks Formation is 2,100 feet of limestone of Mississippian age separated into two formations of the Madison Group; the Lodgepole Limestone (oldest) and the Mission Canyon Limestone. Disconformably overlying the Mission Canyon Limestone is the Big Snowy Group,

900-1,100 feet thick, followed disconformably by the Amsden Formation, 450 feet thick, and the Quadrant Formation 250-300 feet thick. The Big Snowy Group is Mississippian in age; the Amsden and Quadrant Formations are Pennsylvanian in age.

Small surficial deposits of Recent age complete the stratigraphic succession.

Intrusive rocks include two large sills of diorite, several small intrusive bodies of porphyritic andesite, and two small sills of intermediate composition. The intrusive masses are believed to be Late Cretaceous in age. Remnants of a once extensive Tertiary basalt flow cover an area of about one-half square mile.

The earliest recorded structural event was the development of the Beltian geosyncline and the Central Montana trough, which accumulated tremendous thicknesses of Belt strata during Precambrian time. This thick sedimentary wedge and the configuration of the unstable Central Montana trough strongly influenced Laramide tectonism in the Hogback Mountain area.

Most of the structure formed in response to northeast-southwest compression during the Laramide orogeny in Late Cretaceous and Tertiary time. Major thrusting, with yielding to the northeast, occurred first, followed by large-scale folding and more thrusting. The first thrust to form, the

Scout Camp thrust, was intensely folded and overturned. The Moors Mountain thrust, slightly younger and originating west of the Scout Camp thrust, was gently folded. Crustal shortening in the Hogback Mountain area due to Laramide thrusting and folding is estimated to be at least fifteen miles.

Intrusive bodies were emplaced before culmination of Laramide folding but the exact relationship between thrusting, folding, and plutonism is not known.

Post-Laramide deformation is limited to Cenozoic uplift with accompanying gentle northwestward tilting and minor high-angle faulting.

CONTENTS

ILLUSTRATIONS

Plate Page

Figure

TABLES

INTRODUCTION

Purpose

The Hogback Mountain area lies within the Disturbed Belt, a broad zone of folded and faulted rocks that stretches along the eastern front of the Northern Rocky Mountains, structurally below the great Laramide thrusts of Montana. The purpose of this study was to map the geology, and determine the geometry and style of structural deformation of the Hogback Mountain area as part of the Disturbed Belt.

Location and Physiography

The map-area is located about twenty miles northeast of Helena, Montana, in the northern part of the Big Belt Mountains (Fig. 1). It lies entirely within the Hogback Mountain 7½-minute quadrangle, bounded by latitudes 46°45' and 46°52'30" N. and longitudes 111°37'30" and 111°45' W. The mapped area covers all of the Hogback Mountain quadrangle except for about two square miles along the northern border and one-half square mile along the western border.

The terrain in the map-area is rugged, with over 3,500 feet of relief. Elevations range from less than

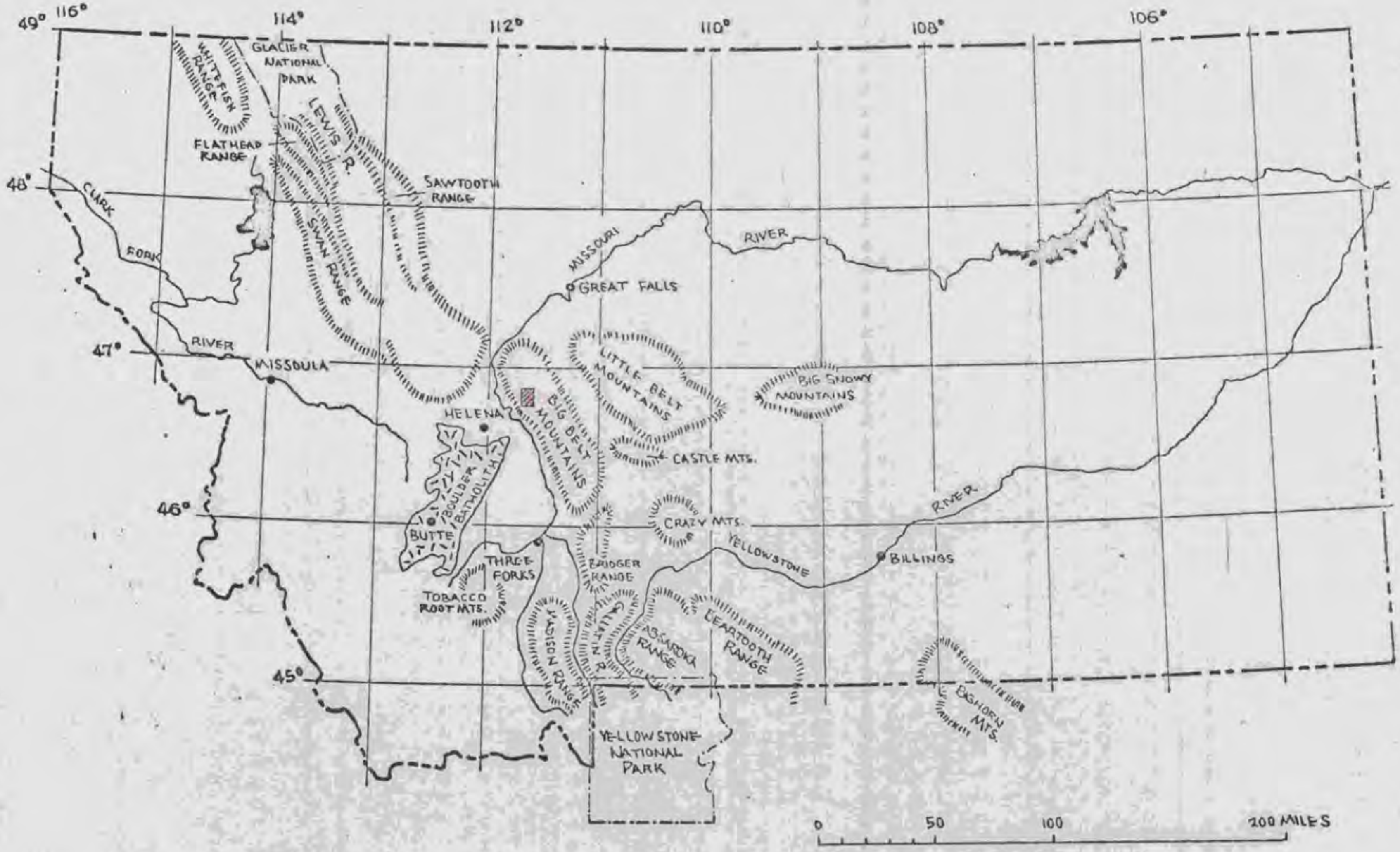


Fig. 1.--Index map of Montana, showing location of Hogback Mountain quadrangle (ruled).

4,300 feet along Trout Creek to over 7,800 feet on Hogback Mountain.

Field Methods and Nomenclature

A total of 42 days were spent in the field during the summer of 1970 involving about 250 miles of traverse, most of which was by foot. Geology was plotted directly on a 1:24,000, 7½-minute topographic map of the Hogback Mountain Quadrangle, Montana. Air photographs with a scale of 1:50,000 were used as a general aid to field mapping. Thicknesses of measured sections were determined by the Brunton compass-Jacob staff method. Other stratigraphic thicknesses were scaled from structure sections.

Particle size classifications used are those proposed by Wentworth (1922). Crystal size nomenclature for precipitated rocks is the same as for particles in clastic rocks. Precipitates with a mean crystal size less than 1/16 mm are termed densely crystalline. The terms shale and mudstone, as used in this report, both imply a consolidated aggregate of at least 50 per cent clay and silt; shale is fissile, mudstone is not. Argillite is defined as a weakly metamorphosed shale. Quartzose implies a sand or sandstone, more than 90 per cent of which consists of quartz grains, not cemented by silica.

A similar sandstone cemented with silica is termed a quartzitic sandstone. Limestone, dolomite, and the rocks intermediate between limestone and dolomite were separated on the basis of their reaction to cold 6N hydrochloric acid:

Limestone: violent effervescence
Dolomitic limestone: brisk, quiet effervescence
Calcareous dolomite: mild emission of CO_2 beads
Dolomite: no effervescence

Terms used for the dip angle of faults are:

Gentle: $<30^\circ$
Moderate: 30°-60°
Steep: $>60^\circ$

Thickness of strata classifications used are those modified from Wengerd (1948) and Kelley (1956).

Massive: >6 feet
Thick-bedded: 1-6 feet
Medium-bedded: 4-12 inches
Thin-bedded: ½-4 inches
Laminated: <½ inch

Previous Work

Geologic mapping in the vicinity of the Hogback Mountain quadrangle includes regional studies to the north by Barnett (1917) and Lyons (1944). Pardee and Schrader (1933) did reconnaissance mapping immediately to the south; an area of about two square miles within the Hogback Mountain quadrangle was included on their map. A more recent and detailed study of the area to the south was done by Mertie and others (1951) in the Canyon Ferry 15-minute quadrangle. Birkholz (1967) and Hruska (1967) mapped areas in the northeastern Big Belt Mountains, and Weinberg (1970) mapped an area just west of the Hogback Mountain area. A small portion of Weinberg's map (four square miles) which extended into the Hogback Mountain quadrangle was remapped for the sake of uniformity. Recently, the four 7½-minute quadrangles immediately to the west and northwest of the Hogback Mountain area have been studied by Robinson and others. To date, only one of these Geologic Quadrangle series maps, the Upper Holter Lake Quadrangle, has been published (Robinson and others, 1969). A generalized structure map of the region has been presented by Robinson and others (1968). Strata in the vicinity have been examined by Deiss (1936), Lochman and Duncan (1944), Gutschick and others (1962), and Lorenz (1962).

Acknowledgments

The author wishes to thank Dr. Lee A. Woodward who suggested the problem, visited the field area, and directed the preparation of this report. Thanks also go to Drs. A. M. Kudo, S. A. Wengerd, G. D. Robinson, W. B. Myers, and M. E. McCallum for critically reviewing this work. Financial assistance was provided by a National Science Foundation Summer Traineeship.

STRATIGRAPHY

Sedimentary rocks in the Hogback Mountain area have an aggregate thickness of around 16,500 feet. The sequence, summarized in Table 1, includes two formations of the Precambrian Belt Series, five formations of Cambrian age, seven formations of Devonian and Carboniferous age, and small deposits of Recent alluvium and colluvium.

Precambrian Rocks

General Statement

In the map-area, the oldest stratified rocks are those of the Precambrian Belt Series. As described by Walcott (1899), the Belt Series in the Little Belt Mountains consists of the following units; Neihart Quartzite (oldest), Chamberlain Shale, Newland Formation, Greyson Shale, Spokane Shale, Empire Shale, Helena Limestone, and Marsh Shale (youngest). In the Hogback Mountain area two Belt formations were identified, the Newland Formation and the Greyson Shale. These rocks, of Middle Proterozoic age (Obradovich and Peterman, 1968), about 1.3 m.y. old, have a composite thickness of approximately 10,700 feet in the map-area.

TABLE 1.--Generalized stratigraphic section, Hogback Mountain area, Montana.

System or Series	Formation	Thickness (feet)	Description
Quaternary	Alluvium	0-50(?)	Clay, silt, and poorly sorted subrounded to angular sand and gravel. Fluvial.
	Colluvium	0-25(?)	Slope wash, landslide debris, and talus.
	Unconformity		
Pennsylvanian	Quadrant Formation	250-300	White to light-gray, thick-bedded, fine- to medium-grained quartzitic sandstone, weathers white to pale-orange. Forms ledges.
	Amsden Formation	450	Yellow-red mudstone, siltstone, and fine-grained, calcareous sandstone grading upward into gray-brown limestone and subordinate varicolored shale and quartzitic sandstone.
	Disconformity		
	Big Snowy Group	900-1,100	Highly varied lithology. Mainly varicolored shale, and impure limestone with subordinate sandstone. Poorly exposed.
	Disconformity		
Mississippian	Madison Group		
	Mission Canyon Limestone	1,200-1,400	Gray-brown, densely crystalline, thick-bedded to massive and indistinctly bedded, slightly fossiliferous and petroliferous limestone. Weathers light-gray. Forms cliffs.
	Lodgepole Limestone	800	Gray-brown, densely crystalline, thin- to medium- and distinctly bedded, very fossiliferous, slightly petroliferous limestone. Weathers yellow-gray to brown-gray. May include as much as 15 feet black shale at base. Forms ledges.
Lower Mississippian and Upper Devonian	Three Forks Formation	150-250	Varied lithology. Lower part mainly varicolored shale with subordinate limestone, siltstone, and mudstone. Upper part orange, flaggy, calcareous siltstone and very fine-grained sandstone. Very fossiliferous. Poorly exposed.
Upper Devonian	Jefferson Dolomite	600-700	Brown to gray-brown, finely to coarsely crystalline, thin- to thick-bedded dolomite. Highly fetid and petroliferous. Weathers brown-gray with a sugary or felted surface. Light brown-gray, dolomitic limestone, 60-80 feet thick at top. Forms ledges and cliffs.
	Disconformity		
Upper Cambrian	Pilgrim Limestone	150-300	Dark-brown to dark-gray, thin- to thick-bedded, densely crystalline limestone. Weathers yellow-gray. Abundant intraformational conglomerates. Forms ledges.
Middle Cambrian	Park Shale	100-250	Green-gray and brown-maroon, lam'nated, slightly micaceous shale. Poorly exposed.
	Meagher Limestone	200-400	Dark-brown to dark-gray, thin- to thick- and unevenly bedded, densely crystalline, orange-mottled limestone. Weathers light-gray to light brown-gray. Forms ledges and cliffs.
	Wolsey Shale	200-350	Olive to green-gray and brown, wavy-bedded, silty highly micaceous shale. Subordinate limestone and quartzitic sandstone. Poorly exposed.
	Flathead Sandstone	150-250	Light-pink to tan, thin- to thick-bedded and cross-bedded, poorly sorted, medium- to coarse-grained subrounded, slightly conglomeratic quartzitic sandstone. Forms ledges.
	Angular Unconformity		
Precambrian (Belt Series)	Greyson Shale	5,300	Dark-gray, brown, yellow-brown, and gray-green, laminated, slightly calcareous shale, argillite, and siltstone. Subordinate light-brown, very fine to fine-grained quartzitic sandstone, and dark-gray to black, densely crystalline limestone.
	Newland Formation	5,500+	Yellow-brown, red-brown, and gray to black, calcareous argillite and silty shale; dark-gray, densely crystalline, slightly dolomitic limestone; subordinate siltstone and very fine-grained quartzitic sandstone. A few thin layers of coarse-grained sandstone at top.

Belt rocks in the area are well exposed but do not commonly form bold outcrops. Typically, smooth gentle slopes are formed in which outcrops are buried under a thin cover of talus or surface mantle. On some of the steeper slopes, such as those along Trout Creek and Soup Creek, subdued cliffs are present.

Most of the Belt rocks in the map-area have been affected by regional, low-grade metamorphism.

Newland Formation

Walcott (1899) proposed the name Newland Limestone for a thick sequence of calcareous strata exposed along Newlan Creek, about eleven miles north of White Sulphur Springs, Montana. The name Newland Formation is used in this report because shale, argillite, and siltstone make up most of the formation. Rocks of the Newland Formation are the oldest exposed in the map-area.

The Newland Formation consists of yellow-brown, red-brown, and gray to black, calcareous argillite and silty shale, dark-gray, densely crystalline, slightly dolomitic limestone, and subordinate siltstone and very fine-grained quartzitic sandstone. The shale and argillite weather gray to yellow-brown whereas the limestone weathers blue-gray. A few thin layers of subangular to subrounded, poorly sorted, coarse-grained, feldspathic sandstone occur near the top of the formation and may represent a tongue of the LaHood Formation, a coarse-grained facies of the Belt Series (McMannis, 1963) deposited along the southern fault-controlled margin of the Central Montana trough (Fig. 2).

The lower part of the Newland Formation consists mainly of laminated to thin-bedded shale, argillite, and siltstone with only a minor amount of limestone. The amount of limestone increases upward in the section with the upper part of the Newland consisting mainly of laminated to medium-bedded shale, argillite, and limestone. Medium- to thick-bedded limestone makes up much of the upper several hundred feet of the Newland; there is a striking contrast between these limestones and the dark shales of the Greyson. Shale and argillite in the lower Newland is much the same as the shale and argillite in the Greyson.

Limestone beds in the upper Newland are cut by numerous calcite veins, and in many places show considerable small-scale folding, although these folds cannot be traced far into the adjacent beds of argillite and shale. Slaty cleavage, which commonly obscures the bedding in the shales and argillites, cuts across the deformed limestone layers. The most prominent cleavage trends approximately N.60° W. and dips steeply to the southwest. Disc-shaped calcareous concretions, up to twenty inches in diameter, several inches thick, and exhibiting cone-in-cone structure, are common in some parts of the formation. Steep slopes formed on the Newland are commonly covered by a loose mantle of buff, platy, lath-shaped fragments of shale and argillite.

Only a partial thickness for the Newland Formation can be given because its base is cut out by a thrust fault in this area. In the southern part of the map-area the Newland is estimated to be 5,500 feet thick; to the northwest, along Soup Creek, the Newland is only 4,000 feet thick. Thus, the thrust cuts upsection to the northwest in the Newland. Pardee and Schrader (1933) estimated a thickness of 4,500 feet for the Newland exposed along Trout Creek, but this figure is probably too low.

The contact between the Newland Formation and the Greyson Shale is gradational and to some extent a matter of interpretation; generally, this transitional zone is about fifty feet thick. The contact is arbitrarily placed above the stratigraphically highest bed of limestone in this zone. Usually, there is a slight topographic break between the resistant limestone units in the upper Newland and the softer shales at the bottom of the Greyson.

Greyson Shale

The Greyson Shale was named by Walcott (1899) for a thick section of dark shale exposed between Greyson Creek and Deep Creek, southeast of Townsend, Montana.

The Greyson consists of dark-gray, brown, yellow-brown, and gray-green, laminated, slightly calcareous shale, argillite, and siltstone, with subordinate light-brown, very fine to fine-grained quartzitic sandstone. These rocks weather gray to red-brown, and are commonly limonite-stained. Subordinate dark-gray to black, thin- to medium-bedded and unevenly bedded, densely crystalline, argillaceous limestone is exposed in the Greyson in the northwestern part of the map-area (thrust plate C, Fig. 3). This limestone weathers blue-gray with deep pits and grooves.

Shale and siltstone in the Greyson commonly show small-scale cross-bedding and scour-and-fill structure. Red-brown to brown-black, blocky fragments of shale and argillite commonly cover steep slopes formed on the Greyson. Slaty cleavage is fairly well developed in some parts of the formation.

About 5,200 feet of Greyson Shale is exposed along Bull Run Gulch in the southwestern part of the map-area. The Greyson is apparently in conformable contact with the Spokane Shale about 200 feet off the southwest corner of the Hogback Mountain quadrangle, which would give an approximate thickness of 5,300 feet for a complete Greyson section. This section has been affected by faulting (one steep fault, one thrust fault) but it is believed that the section added by the thrust fault has been approximately eliminated by the steep fault, and that the above thickness is fairly representative for the Greyson in this area. In thrust plates A, B, and C (Fig. 3) the Greyson lies on thrust faults which cut out most of the formation. In thrust plates A and B the upper contact of the Greyson is an unconformity at the base of the Cambrian Flathead Sandstone.

Precambrian-Cambrian Unconformity

A regional unconformity exists between rocks of the Belt Series and the Cambrian Flathead Sandstone. In the Elkhorn Mountains (Klepper and others, 1957), the Townsend Valley (Freeman and others, 1958), and the Canyon Ferry quadrangle (Mertie and others, 1951), the unconformity cuts stratigraphically higher in Belt rocks to the north. However, along Avalanche Creek, in the east-central part of the Canyon Ferry quadrangle, the trend is reversed and the unconformity cuts stratigraphically lower to the north. In the central part of the Canyon Ferry quadrangle the Flathead Sandstone rests on Helena Limestone. The Flathead lies on Empire Shale near the Canyon Ferry dam and along Magpie Gulch (Mertie and others, 1951). Along Trout Creek, the Flathead lies on

Spokane Shale (Pardee and Schrader, 1933), and along Beaver Creek the Flathead lies on Greyson Shale (Weinberg, 1970). The Flathead also lies on Greyson in the Hogback Mountain quadrangle.

Regionally, from east to west, the Belt-Flathead unconformity cuts stratigraphically higher in Belt rocks (Deiss, 1936).

Cambrian Rocks

General Statement

Early work on Cambrian rocks near Three Forks, Montana was done by Peale (1893). The names used in this report follow those applied by Weed (1899b) for Cambrian rocks in the Little Belt Mountains, Montana, with redefinitions by Deiss (1936).

Cambrian rocks, 800-1,550 feet thick in the Hogback Mountain area, have been divided into five formations. The basal unit is the Flathead Sandstone followed by the Wolsey Shale, Meagher Limestone, Park Shale, and Pilgrim Limestone. The first four formations are of Middle Cambrian age, and the fifth formation, the Pilgrim Limestone, is of Late Cambrian age (Deiss, 1936).

The Cambrian section is much deformed, and mostly upside down. Spotty exposures and intense deformation make it difficult to get a complete picture of the stratigraphy or to obtain precise thickness measurements. In the southeastern part of thrust plate B (Fig. 3) the Cambrian section seems to be too thin, probably the result of tectonic thinning. Most workers in the area report an average thickness of about 1,500 feet for the Cambrian section (Mertie and others, 1951; Weinberg, 1970; Deiss, 1936; Knopf, 1963). However, Hruska (1967) reports a Cambrian section only 760 feet thick in an area ten to fifteen miles east of the Hogback Mountain quadrangle.

Flathead Sandstone

The type section for the Flathead Sandstone is near Flathead Pass, Bridger Range, Montana (Peale, 1893). In the Hogback Mountain area, the Flathead consists of light-pink to tan, thin- to thick-bedded, poorly sorted, medium- to coarse-grained, slightly conglomeratic quartzitic sandstone. Purple bands and, locally, crossbedding are common. The bottom part of the formation is typically deep red or brown due to a high concentration of hematite. The Flathead characteristically forms strike ridges or low ledges.

The upper contact of the Flathead with the Wolsey Shale was not observed but apparently is conformable (Deiss, 1936). The Flathead is 150-250 feet thick.

Wolsey Shale

The type section for the Wolsey Shale is along Sheep Creek in the Little Belt Mountains (Weed, 1899b).

The Wolsey consists mainly of olive to green-gray and brown, wavy-bedded, silty, highly micaceous shale. Most of the micaceous material has been altered to chlorite. Worm trails or casts are common. Thin interbeds of limestone, and red-brown quartzitic sandstone are locally present in parts of the Wolsey. The limestone resembles the Meagher Limestone but occurs rarely in beds as much as several feet thick. The quartzitic sandstone is reddish and closely resembles the lower part of the Flathead Sandstone.

The Wolsey, poorly exposed and normally revealed only by the presence of greenish-brown and highly micaceous soil, is easily eroded and commonly forms prominent strike valleys between the more resistant formations above and below. Because of its incompetent nature, the Wolsey acts as a receptive host for sills.

The upper contact of the Wolsey with the Meagher Limestone was not observed but apparently is conformable (Deiss, 1936). The thickness of the Wolsey varies within wide limits due to thickening and thinning by deformation;

it is estimated to be 200-350 feet thick.

Meagher Limestone

Weed (1899b) named the Meagher Limestone but gave a very loosely defined type section. South Hill, in the Little Belt Mountains, is the emended type section (Deiss, 1936).

The Meagher consists of dark-brown to dark-gray, thin- to thick-bedded and unevenly bedded, densely crystalline, orange-mottled limestone. The mottled appearance is probably caused by an orange, calcareous silt deposited along bedding planes or partings.

Medium- to coarse-grained oolitic(?) zones are present in some parts of the Meagher, as are worm(?) borings up to one-half inch in diameter. Intraformational conglomerates occur in the Meagher but they are not common. Some of the darker beds have a slight petroliferous odor when freshly broken. The Meagher weathers light-gray to light brown-gray, and appears massive from a distance. Where the Paleozoic section is inverted, the Meagher forms the uppermost and boldest ledges and cliffs.

The upper contact of the Meagher was not observed but is conformable (Deiss, 1936). The Meagher is considerably deformed and its thickness varies greatly; it is estimated to be 200-400 feet thick.

Park Shale

Weed (1899b) named the Park Shale but did not cite a type section. In the Hogback Mountain area, the Park consists of green-gray and brown-maroon, laminated, slightly micaceous shale. The Park is very poorly exposed but its presence can usually be determined by green shaly soil. Strike valleys or saddles are formed on the formation between the more resistant units above and below.

Although not observed, the upper contact of the Park is probably conformable with the Pilgrim Limestone. Poor exposures and tectonic thickening and thinning make it difficult to obtain a reliable thickness for the Park, but it is estimated to be 100-250 feet thick.

Pilgrim Limestone

The type locality for the Pilgrim Limestone is along Pilgrim Creek in the Little Belt Mountains (Weed, 1899b).

The Pilgrim consists of dark-brown to dark-gray, thin- to thick-bedded, densely crystalline limestone. It weathers yellowish-gray, and in places shows very regular bedding. Oolitic and medium- to coarse-grained zones are common, as are flat-pebble intraformational conglomerates. Orange-mottling, common in the Meagher, also occurs in the Pilgrim but to a much lesser degree. Thin, silty shale partings commonly occur between the beds of limestone. The Pilgrim is a ledge-former.

A more-yellowish weathered tone, more regular bedding, less orange-mottling, and abundant flat-pebble intraformational conglomerate beds distinguish the Pilgrim from the Meagher where complete and well exposed sections are seen. In structurally complex areas, where only partial sections are seen, it is almost impossible to distinguish between the Pilgrim and the Meagher.

The Pilgrim Limestone is estimated to be 150-300 feet thick. Thickness variations in the Pilgrim are probably due to pre-Devonian erosion. The upper contact of the Pilgrim is an unconformity at the base of the Jefferson Dolomite.

Cambrian-Devonian Unconformity

In much of southwestern Montana, Cambrian and Devonian strata are separated by a regional unconformity between the Cambrian Red Lion Formation (Emmons and Calkins, 1913; age equivalent of the Snowy Range Formation) and the Devonian Maywood Formation (Emmons and Calkins, 1913; age changed from Silurian(?) to Devonian after Lochman, 1950). The term "Dry Creek Shale" has often been used for strata lying between the Pilgrim and Jefferson (Deiss, 1936; Lochman and Duncan, 1944), but this term is now restricted to the basal member of the Snowy Formation (Grant, 1965), as originally named and described by Peale (1893).

In the map-area, neither the Red Lion nor the Maywood were observed, so the Cambrian-Devonian unconformity is between the Pilgrim Limestone and Jefferson Dolomite. The Red Lion has probably been removed by pre-Devonian erosion (Lochman and Duncan, 1944), and the Maywood is probably absent because of nondeposition or tectonic squeezing. It should be noted that the Pilgrim-Jefferson contact is very poorly exposed, and that pods or lenses of either Red Lion or Maywood could be present in the map-area. Deiss (1936) described sixty-two feet of Dry Creek(?) strata about one-fourth mile west of the map-area, along Beaver Creek.

Devonian Rocks

Jefferson Dolomite

Peale (1893) named the Jefferson Dolomite but did not cite a formal type section. Devonian strata on the north side of the Gallatin River at Logan, Montana have generally been accepted as the principal reference section for the Jefferson (Sloss and Laird, 1947).

The Jefferson Dolomite consists of brown to gray-brown, finely to coarsely crystalline, thin- to thick-bedded dolomite, with subordinate light brown-gray dolomitic limestone and calcareous dolomite. The uppermost 60-80 feet (Birdbear Member(?) of Sandberg and Hammond, 1958) consists of light brown-gray dolomitic limestone, and is a prominent ledge-former. When freshly broken, the Jefferson produces a highly fetid, petroliferous odor. The Jefferson weathers brown-gray with a felted or sugary surface, and normally shows deep weathering along bedding planes and joints. The Jefferson, particularly the upper part, forms ledges and cliffs.

The upper contact of the Jefferson is conformable with the overlying Three Forks Formation. In thrust plate D (Fig. 3) the Jefferson is estimated to be 600-700 feet thick. In thrust plate B, however, the Jefferson has been considerably deformed and tectonically thinned; its average thickness is only 300-400 feet.

Devonian-Mississippian Rocks

Three Forks Formation

Because of its varied lithology, the Three Forks Shale (Peale, 1893) was renamed the Three Forks Formation by Haynes (1916); it is used in the latter context in this report. The type section for the Three Forks Formation is at the confluence of the three forks of the Missouri River. Berry (1943) called the yellow sandstone at the top of the Three Forks the Sappington and considered it a distinct formation. However, most workers now consider the Sappington to be a member of the Three Forks Formation (Sloss and Laird, 1947). In the map-area, the Sappington was easily recognized but is mapped with the Three Forks as a single unit.

The lower part of the Three Forks Formation consists mainly of green to brown-black shale, pale-orange to yellow thin-bedded silty limestone, and subordinate red and yellow-brown siltstone and olive-gray mudstone. The middle part of the Three Forks consists of green-yellow to black, friable to hard, locally carbonaceous, calcareous shale and brown-purple-gray brecciated limestone. The upper part of the Three Forks is made up of orange, flaggy, thin- to medium-bedded, calcareous siltstone and very fine-grained sandstone (Sappington Member).

A true thickness for the Three Forks is hard to determine because of the intense tectonic deformation. The 490 feet measured on Hogback Mountain seems much too thick, and probably represents considerable tectonic thickening. It is estimated that the Three Forks is 150-250 feet thick.

The following measured section of the Three Forks Formation was taken on the north side of Hogback Mountain in the SE¼ Sec. 4, T.12N., R.1W. (Pl.1).

Lodgepole Limestone.
Three Forks Formation:

	Thickness (feet)
Siltstone and very fine-grained sandstone, orange, flaggy, calcareous.	60
Shale, black, hard.	30
Limestone, brown-purple-gray, brecciated	10
Shale, green-yellow, friable, calcareous.	20
Limestone, brown-purple-gray, finely crystalline, thin-bedded, brecciated.	15
Shale, black, friable, and carbonaceous at bottom; dark-olive, hard, fissile at top.	50
Limestone, orange, silty; brown to black shale	100
Shale, green-brown; minor yellow-brown siltstone	175
Siltstone, red; subordinate light-green, calcareous siltstone . . .	5
Dolomite, light brown-gray, thin-bedded, finely crystalline, calcareous	25
Total thickness	490

Jefferson Dolomite.

The Three Forks Formation is rich in fossils, particularly brachiopods. <u>Scalarituba missouriensis</u>, probably a worm-like organism, was found at the south end of Trout Creek Canyon where a stratigraphic assignment would be very difficult in the absence of this definitive fossil. Strike valleys and swales are formed on the Three Forks Formation, which is usually poorly exposed.

Controversies over the exact location of the Devonian-Mississippian boundary in southwestern Montana have existed since the work of Peale (1893). Berry (1943) placed the boundary between the lower shales of the Three Forks Formation and the sandstone of the Sappington. Gutschick and others (1962) consider the Devonian-Mississippian boundary to be within the Sappington Member. At any rate, the lower part of the Three Forks Formation is Upper Devonian and the upper part is Lower Mississippian.

Carboniferous Rocks

General Statement

Carboniferous rocks, divided into five units, are 3,600-4,050 feet thick in the map-area. Two thick formations of the Madison Group, the Lodgepole Limestone and the Mission Canyon Limestone, make up the lower part of the Carboniferous. In ascending order, the rest of the Carboniferous consists of the Big Snowy Group, the Amsden Formation, and the Quadrant Formation.

The Madison Group and the Big Snowy Group are Mississippian in age. The Mississippian-Pennsylvania boundary occurs at the regional unconformity between the Big Snowy Group and the Amsden Formation (Maughan and Roberts, 1967). The Amsden and Quadrant Formations are Pennsylvanian in age.

Madison Group

Peale (1893) named and first described the Madison Formation from a thick sequence of limestone in the Madison Range, Montana. Later, Collier and Cathcart (1922) raised the Madison to group rank and divided it into two formations, the thin-bedded Lodgepole Limestone (lower) and the massive Mission Canyon Limestone (upper). These units have been mapped separately except for a small, intensely deformed area in Trout Creek Canyon where they have been mapped as a single unit.

Lodgepole Limestone. The Lodgepole Limestone consists of gray-brown, densely crystalline, mostly thin-bedded, highly fossiliferous limestone that weathers yellow-gray to brown-gray. At several places in the map-area, the Lodgepole is underlain by as much as fifteen feet of black shale. This shale unit is correlated with the Little Chief Canyon Member of Knechtel and others (1954), but has been included in the Lodgepole for mapping purposes. Where present, the Little Chief Canyon Member appears to be conformable with both the underlying Three Forks Formation and the overlying Lodgepole; where absent, there appears to be a disconformity between the Three Forks and the Lodgepole, but this probably represents only a brief hiatus.

Fossils, including a wide variety of brachiopods, fragments of crinoid stems, corals, and bryozoans, are abundant throughout the Lodgepole. Yellow-gray to red-brown, calcareous mudstone partings, 1-2 inches thick, commonly separate limestone beds, particularly in the lower part of the formation. More coarsely crystalline or clastic beds occur in the Lodgepole although they are not common; when freshly broken they usually have a slightly petroliferous odor.

The Lodgepole is distinctly and evenly bedded. It resembles the Cambrian Meagher and Pilgrim Limestones but distinction is easily made on the basis of fossils. Usually the Lodgepole forms ledges and tree-covered slopes beneath the massive cliffs of the Mission Canyon Limestone. The upper contact of the Lodgepole with the Mission Canyon is conformable. The Lodgepole is estimated to be 800 feet thick.

Mission Canyon Limestone. The Mission Canyon Limestone consists of gray-brown, densely crystalline, thick-bedded to massive and indistinctly bedded limestone that weathers light-gray. Fossils are found in the Mission Canyon but they are not common. When freshly broken, the Mission Canyon has a slight, but distinct, petroliferous odor. The upper part of the formation is cherty, and caves commonly form in the upper several hundred feet. In areas of gentle dips the Mission Canyon is poorly exposed, forming a rolling terrain densely covered with trees and grass. Along escarpments or in areas of steep dips, such as in Trout Creek Canyon, the Mission Canyon forms the highest and boldest cliffs.

The upper contact of the Mission Canyon with the Big Snowy Group was not observed but apparently represents an unconformity (Maughan and Roberts, 1967). Determining the thickness of the Mission Canyon is difficult because of the intense internal deformation. Thicknesses given nearby by Robinson and others (1969) and Weinberg (1970) of 1,200 and 1,400 feet, respectively, are probably representative of the thickness of the Mission Canyon in the map-area.

Big Snowy Group

Scott (1935) defined the Big Snowy Group as consisting of the following three formations, in ascending order: Kibbey Sandstone (Weed, 1899a), Otter Shale (Weed, 1892), and Heath Shale. The Kibbey and Otter were named by Weed for exposures in the Little Belt Mountains, and the Heath was named by Scott for a unit exposed in the Big Snowy Mountains, Montana. Rocks of the Big Snowy are confined to central Montana, their northwesternmost extent being the vicinity of Helena, Montana (Maughan and Roberts, 1967, Pl. 3).

Because of inadequate exposures, and facies changes between the northern Big Belt Mountains and the type section to the east, the three formations of the Big Snowy Group have not been mapped separately, but are shown as a single, undivided unit (Pl. 1). The lower part of the Big Snowy is poorly exposed. The middle part consists of black, gray, purple, and brown shale and interbedded dark-gray to black, petroliferous limestone. The limestone weathers yellow-gray. The upper part of the Big Snowy consists of dark-gray to black, petroliferous, argillaceous limestone; black shale with subordinate red and brown, ferruginous shale; gray-brown, calcareous, very silty, fine-grained sandstone; and gray-brown to yellow-gray limestone. Strike valleys form on the soft shales of the Big Snowy which also act as a receptive host for intrusive bodies.

The upper contact of the Big Snowy is an unconformity at the base of the Amsden Formation. Poor exposures, deformation, and intrusive bodies in the Big Snowy make it difficult to obtain a reliable thickness, but it is estimated to be 900-1,100 feet thick.

Amsden Formation

Darton (1904) named and described the Amsden Formation for a sequence of red mudstone and limestone exposed in the northern Bighorn Mountains, Wyoming.

The lower part of the Amsden consists of yellow-red to red mudstone, siltstone, and fine-grained calcareous sandstone. A thin, red-brown, limestone-pebble conglomerate is exposed at the base of the section. The formation is more calcareous in the upper section, with the upper part consisting mainly of gray-brown limestone and thin interbeds of red-purple and green-gray shale. Interbeds of quartzitic sandstone occur near the top of the formation. In areas of steep dips, a steep slope is formed on the Amsden between the resistant beds of the Quadrant Formation and the soft shales of the Big Snowy Group.

The upper contact of the Amsden Formation with the Quadrant Formation was not observed but apparently is conformable (Scott, 1935; Robinson and others, 1969). The Amsden is estimated to be 450 feet thick.

Quadrant Formation

Weed (1896) named the Quadrant Quartzite for the post-Madison, pre-Permian rocks on Quadrant Mountain in the northwestern part of Yellowstone National Park. Scott (1935) drastically restricted Weed's original definition by limiting the Quadrant to the quartzitic sandstone beds just below the

Permian Phosphoria Formation. His redefinition of Weed's Quadrant into the Big Snowy Group, Amsden Formation, and Quadrant Formation is widely accepted, and is used in this report.

The Quadrant Formation consists mainly of white to light-gray, thick-bedded, fine- to medium-grained quartzitic sandstone that weathers white to pale-orange. Subordinate light-gray, sandy, dolomitic limestone occurs near the base. A prominent ledge- and ridge-former, the Quadrant is estimated to be 250-300 feet thick.

Surficial Deposits

Recent alluvium, of fluvial origin, covers the bottom of most of the larger gulches and stream valleys in the map-area. These deposits, consisting of clay, silt, and poorly sorted, subrounded to angular sand and gravel, generally reflect the composition of rock units exposed nearby.

Colluvium, a heterogeneous mixture of unconsolidated debris, commonly masks the underlying bedrock on slopes and at higher elevations. These mass-wasting deposits consist of fine to coarse slope wash, landslide debris, and talus. Only the largest and thickest deposits are mapped unless they cover important contacts or faults.

IGNEOUS ROCKS

General Statement

Igneous rocks, covering less than one square mile of the map-area, include small remnants of a once extensive basalt flow and two large sills of diorite emplaced into the Big Snowy Group. Also present are three small dikes and sills of porphyritic andesite which have been intruded into Belt rocks, and two small sills of intermediate composition emplaced into the Wolsey Shale.

Most of the intrusive bodies have been emplaced into shale or shaly units such as the Newland Formation, Greyson Shale, Wolsey Shale, and Big Snowy Group. Field relations suggest that the large sills of diorite were emplaced in the Big Snowy Group prior to the culmination of Laramide tectonism. These sills show considerable deformation, the result, probably, of Laramide folding of the weak and incompetent shales of this group.

The exact relationship between plutonism and tectonism is obscure. Robinson and others (1968) state that, during the Laramide orogeny, plutonism, volcanism, and tectonism were closely related in this part of Montana, beginning and ending within a few million years of each other, and taking place during the last 20 m.y. of the Cretaceous. The intrusive rocks in the map-area, therefore, are considered to be Late Cretaceous in age.

The basalt, which has not been affected by Laramide deformation, is Tertiary in age and probably equivalent to the Tertiary flows mapped by Hruska (1967) to the east.

Diorite

Two sills of dioritic composition have been intruded into the Big Snowy Group in the northern part of the map-area. The largest sill is about 1½ miles long and 200-400 feet thick; the other is 1,400-1,800 feet long and 50-150 feet thick. These rocks have been highly altered and deeply weathered. In hand specimen, they are greenish-black and fine-grained. In thin-section, the rocks show considerable deformation and shearing.

These rocks are composed of 60-65 per cent plagioclase, 20-25 per cent clinopyroxene, 2 per cent pale red-brown biotite, and 2 per cent opaque minerals (mostly iron oxides). The plagioclase, which has been highly altered to sericite and clay, is mostly oligoclase (An_{25}) although the original composition may have been more calcic. Also present is chlorite (2 per cent), probably derived from the pyroxene, quartz (6 per cent), and calcite (3 per cent).

Small Dikes and Sills

Three small intrusive bodies have been intruded into Belt strata; however, an abundance of float suggests the presence of many more. These small dikes and sills range up to fifteen feet in thickness, are deeply weathered, and usually highly altered. Typically, the rocks are greenish-gray with phenocrysts of chlorite in an aphanitic groundmass. They usually weather green-brown.

The average composition of these rocks is 35 per cent plagioclase, 2-4 per cent clinopyroxene, 1-3 per cent greenish-brown hornblende, 12-15 per cent chlorite, 5 per cent calcite, 5 per cent opaque minerals, and 35 per cent groundmass. The plagioclase is usually slightly sericitized and saussuritized, and consists mainly of euhedral to subhedral prisms and laths of oligoclase (An_{20-30}). The chlorite has probably been derived from the alteration of pyroxene and hornblende. Magnetite is the most common opaque mineral. Accessory minerals include quartz (1 per cent), biotite (tr-1 per cent), penninite (tr), and apatite (tr).

Two sills have been intruded into the Wolsey Shale, which seems to act as a receptive host for small intrusive bodies. These sills, which are very poorly exposed, are fine- to coarse-grained and of intermediate composition.

Basalt

Basalt is the most common igneous rock in the map-area, covering an area of about one-half square mile. In hand specimen the rock is black, weathers red-brown to dark brown, and usually shows flow structure.

These rocks range from aphanitic to diabasic with pilotaxitic texture. They contain 65 per cent plagioclase (An_{60}), 15 per cent clinopyroxene, 2 per cent pale red-brown biotite, 3 per cent green, red-brown, and yellow-brown palagonite, and 10 per cent opaque minerals (mostly magnetite).

Other constituents include 1 per cent chlorite, which has probably been derived from the pyroxene, 1 per cent calcite, 1 per cent green-brown to red-brown iron-rich alteration product, and trace amounts of apatite and secondary(?) green biotite.

STRUCTURE

Precambrian Structure

Near the end of the Precambrian, the Central Montana trough (Fig. 2; usage of Sloss, 1950, and referred to as the Central Montana Belt embayment by McMannis, 1963) was uplifted and subjected to erosion. This sedimentary basin, essentially a west-plunging synclinorium with a fault-controlled southern margin, retained its original structure during uplift with the result that the younger rocks in the middle of the basin were protected and those on the flanks were removed by erosion. The east-west axis of the uplifted basin must have passed through the central part of the Canyon Ferry quadrangle (46°38' N.) during Cambrian sedimentation, for it is here that the Precambrian-Cambrian unconformity is found stratigraphically highest in Belt strata (Mertie and others, 1951, Pl. 1).

The Hogback Mountain area, lying north of 46°38' N. and considerably west of the easternmost exposures of Belt strata in the Little Belt Mountains, was situated in the western part of, and on the northern flank of the Central Montana trough during Precambrian time (Fig. 2).

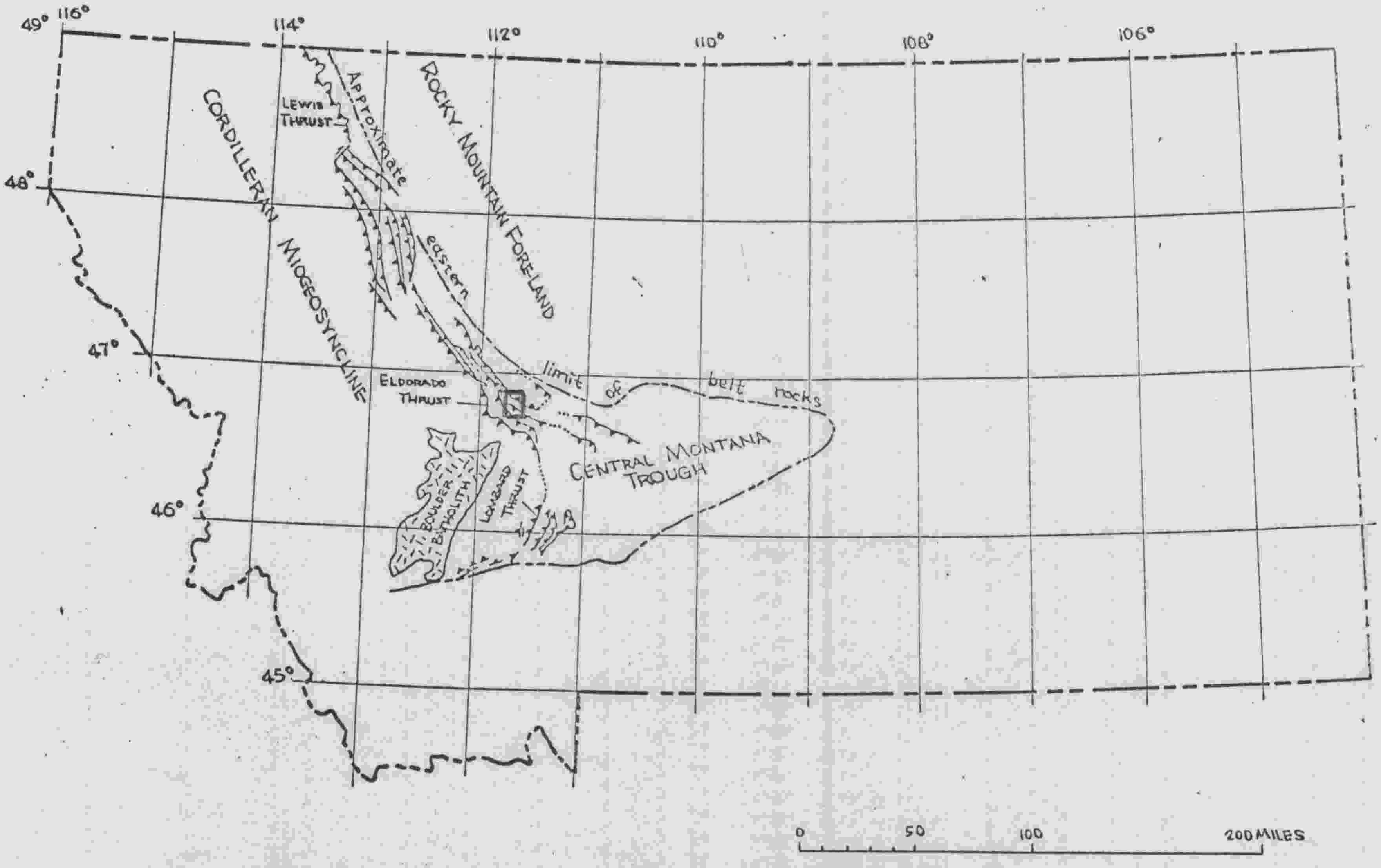


Fig. 2.--Generalized tectonic map of the Disturbed Belt, Montana. Hogback Mountain quadrangle outlined in red.

Late Paleozoic Structure

During Late Mississippian sedimentation, the eastern part of the Central Montana trough (also called the Big Snowy basin or Big Snowy embayment) was strongly negative. Sloss (1950) states that, during this time, the Central Montana trough was an eastward extension (exogeosyncline) of the Cordilleran geosyncline onto the craton.

Laramide Structure

General Statement and Regional Setting

The Hogback Mountain area lies within the Disturbed Belt of Montana which is the zone of contact between the Cordilleran miogeosyncline and the Rocky Mountain foreland (Fig. 2). Along this zone, miogeosynclinal rocks have been thrust eastward over thinner sections of correlative foreland rocks during the Laramide orogeny. The Disturbed Belt is defined as the deformed foreland in front of, and structurally below the zone of frontal breakthrough, marked by the well-known Lewis, Eldorado, and Lombard thrusts. In general, the Disturbed Belt is characterized by west- to southwest-dipping thrusts and north- to northwest-trending folds, with the intensity of deformation lessening towards the east and northeast.

During Precambrian time, thick sequences of Belt strata were accumulated in the north-south Beltian geosyncline and the east-projecting Central Montana trough (Fig. 2). As recognized by many workers, the geometry and thickness of this sedimentary wedge of Belt strata controlled, or at least strongly influenced, Laramide tectonism in Montana. At the northern end of the Big Belt Mountains, about where the Central Montana trough intersects the Cordilleran geosyncline, there is a change in the structural style of the Disturbed Belt. The zone of frontal thrusting, which from Glacier National Park to the northern end of the Big Belt Mountains conforms closely to the zero isopach contour of Belt rocks (Fig. 2), cuts perpendicularly across Belt strata in the Central Montana trough. Following the western flank of the Big Belt Mountains, this zone of thrusts apparently terminates in the Three Forks basin at the fault-controlled southern margin of the Central Montana trough (Robinson, 1959).

Other noticeable changes in structural style include a considerable widening of the Disturbed Belt to the east, following the trend of the northern margin of the Central Montana trough, and bifurcation of major thrusts in the Disturbed Belt into south-trending and southeast-trending zones (Fig. 2). The south-trending zone is the zone of frontal breakthrough; the southeast-trending zone, which angles across the Hogback Mountain area, bends slightly to the east as it follows the trend of the Central Montana trough.

The time interval of the Laramide orogeny ranges widely from place to place; according to Robinson and others (1968) this event occurred during the last 20 m.y. of the Cretaceous in the Hogback Mountain area.

Faults

For convenience of discussion, the six major thrust plates of Laramide origin in the Hogback Mountain area have been designated, in clockwise order, as thrust plates A, B, C, D, E, and F (Fig. 3).

There are three major Laramide thrust faults in the Hogback Mountain area: the Scout Camp thrust, the Moors Mountain thrust, and the Jim Ball Basin thrust. The Scout Camp thrust traverses the map-area twice, forming a half-fenster open to the southeast (Fig. 3). The Moors Mountain thrust cuts across the northwest and southwest corners of the map-area; the Jim Ball Basin thrust forms a wide loop in the northeastern part of the quadrangle.

The Scout Camp thrust is a folded thrust in which rocks as old as Precambrian have moved northeastward over

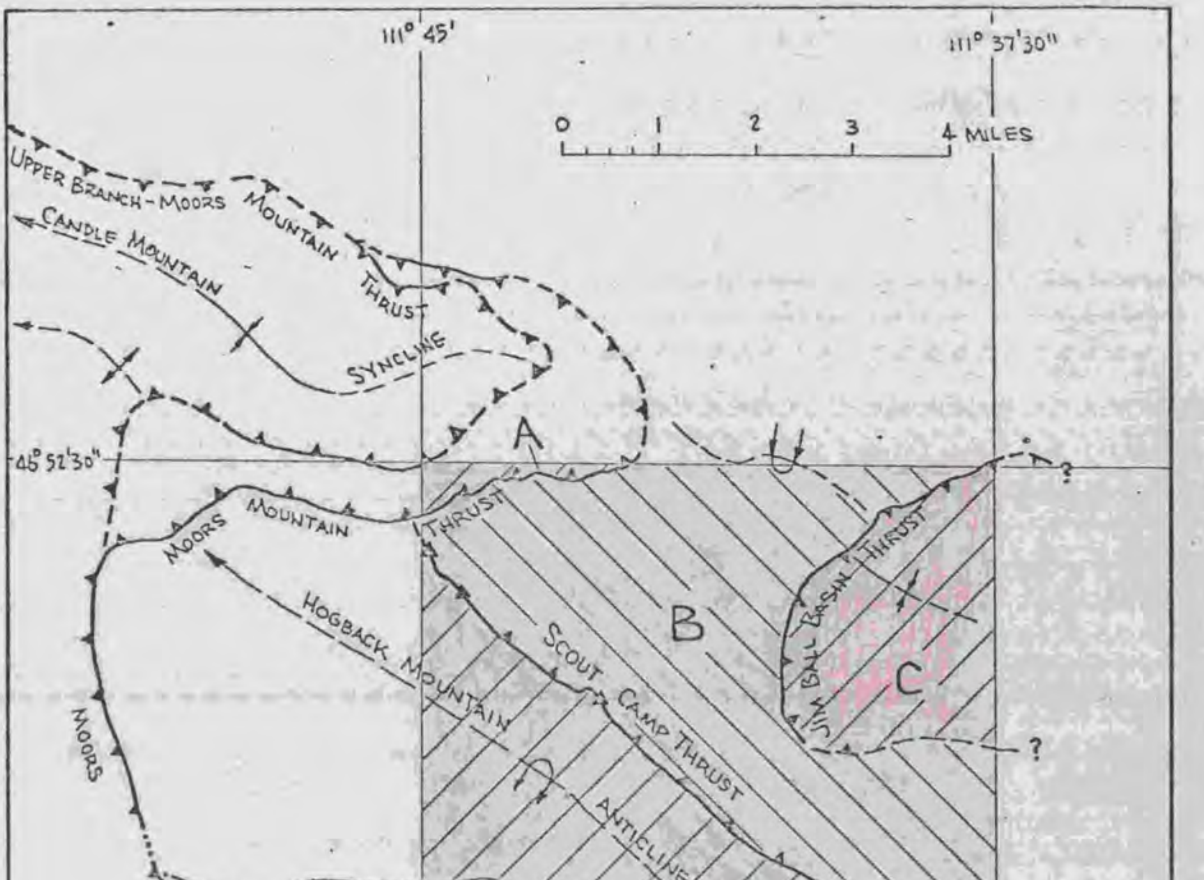


Fig. 3.--Map of the major Laramide tectonic features in the Hogback Mountain area. Letters A, B, C, D, E, and F identify the six tectonic plates of Laramide origin in the Hogback Mountain quadrangle (ruled). Partially based on reconnaissance map compiled by W. B. Myers, U.S. Geol. Survey, 1957, unpublished.

intensely and complexly folded rocks as young as Mississippian. The upper plate of the Scout Camp thrust is relatively undeformed where the thrust has not been folded (thrust plate E); where the thrust is folded the upper plate is considerably deformed (thrust plate B). Folding and erosion of the Scout Camp thrust has exposed the lower plate (thrust plate D).

On the southwest side of thrust plate D, the Scout Camp thrust dips gently to the southwest, as seen by the sinuous fault trace. Calculations show the dip of the fault surface to be 23° to the southwest near Trout Creek, 16° to the southwest south of Soup Creek, and 26° to the southwest north of Soup Creek. On the northeast side of thrust plate D, the Scout Camp thrust dips very steeply, and in places is overturned (Fig. 4). Here, the fault trace is fairly straight with an average strike near N.55° W.

Many small tectonic slices have been caught along the Scout Camp thrust, particularly between thrust plates D and E and involving Lodgepole Limestone; these will be discussed further in the section on folds. Maximum stratigraphic separation on the Scout Camp thrust is about 13,000 feet; the slip could not be determined. There is a marked topographic expression of the fault trace which can usually be seen on air photographs. Along the Scout Camp thrust,

Fig. 4.--View south of Hogback Mountain, showing Scout Camp thrust; Hogback Mountain anticline, and inverted Belt-Paleozoic section.

in the upper part of Beartrap Gulch, there is a road cut in a microbrecciated gouge zone of undetermined thickness which has been bleached almost white. Other exposures of the Scout Camp fault surface and signs of deformation such as drag folds, breccia, gouge or mylonite are rare.

The Moors Mountain thrust (Fig. 5) places slightly deformed Greyson Shale on rocks as young as Pennsylvanian. In the northwest corner of the map-area this thrust lies on intensely folded rocks as old as the Cambrian Flathead Sandstone and as young as the Pennsylvanian Amsden Formation. Calculations show the thrust to dip 22° N., with a minimum stratigraphic separation of 5,000 feet.

In the southwest corner of the map-area, the Moors Mountain thrust is inferred from topography and vegetation changes. Mapping in the adjacent Nelson 7½-minute quadrangle has confirmed the presence of this fault which is a bedding-plane or near bedding-plane thrust placing Greyson on Greyson (W. B. Myers and M. E. McCallum, oral commun., 1971).

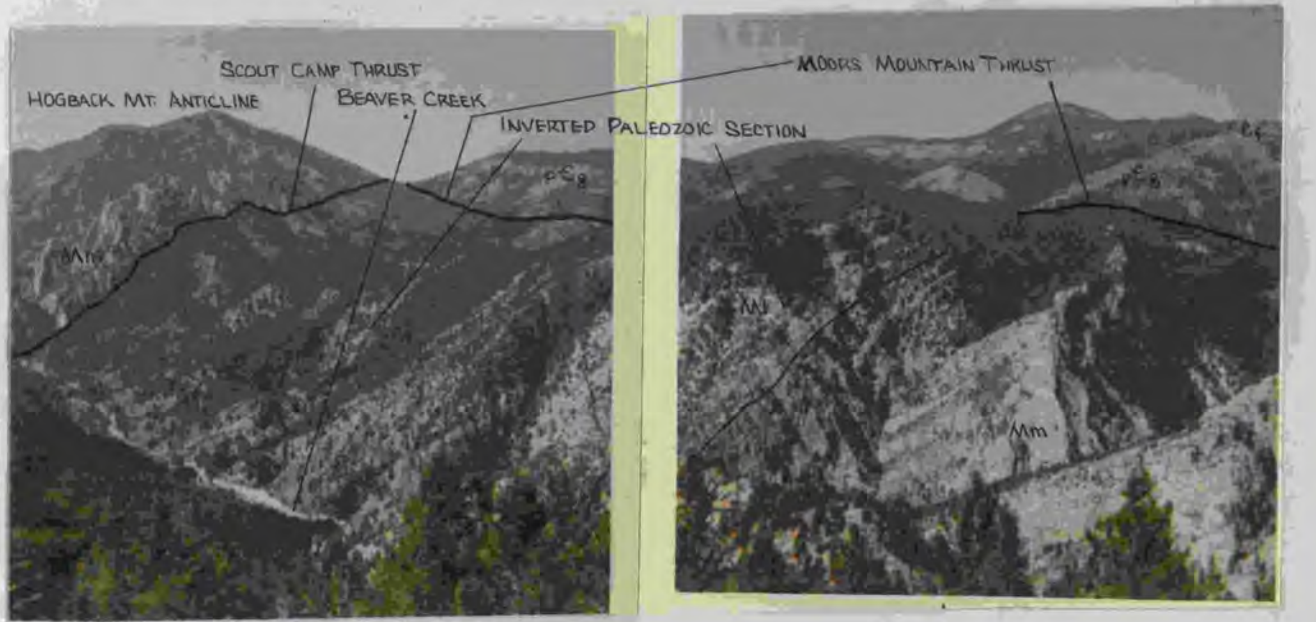


Fig. 5.--View north to northwest from Hogback Mountain, showing Hogback Mountain anticline, inverted Paleozoic section, Moors Mountain thrust, Scout Camp thrust, and chevron folding in the Mission Canyon Limestone.

The stratigraphic separation is not known for this part of the Moors Mountain thrust but it is probably not large because the thickness of the Greyson does not seem to be appreciably affected.

The Jim Ball Basin thrust, which may be correlative with the Moors Mountain thrust, places gently folded Greyson Shale on folded rocks as young as the Mississippian Mission Canyon Limestone. The minimum stratigraphic separation is 4,200 feet. It is not known if the Jim Ball Basin thrust forms a klippe, but this is likely.

There are numerous minor faults in the map-area. At the head of Soup Creek, a steep thrust (reverse) fault in the Jefferson Dolomite trends N.30° W. The stratigraphic displacement on this fault is several hundred feet. An east-trending, left-slip, vertical tear fault, about a mile long but involving only small displacement, cuts the Meagher Limestone just south of Beaver Creek (Fig. 6). This fault is probably of Laramide origin and developed in response to intense folding of the Meagher.

There are three small thrust faults in the map-area which were probably formed in response to internal adjustment within the strongly deformed thrust plate B. One is located on the northwest side of Indian Flats. This fault trends N.45° E. and cuts stratigraphically lower to the northeast,

Fig. 6.--Folding and faulting in the Meagher Limestone. View northeast from Hogback Mountain.

eventually cutting out the Meagher Limestone. The minimum stratigraphic separation is 250 feet. In the upper plate of this thrust there is a small east-trending, right-slip, tear fault which dips moderately to the south.

The second internal thrust within thrust plate B is located in the northwest corner of the quadrangle. This small thrust trends about N.70° W., placing Jefferson Dolomite on inverted Meagher Limestone, Park Shale, and Pilgrim Limestone. The fault dies to the southeast, ending within the Jefferson.

The other internal thrust is located south of Grouse Ridge, along Indian Creek. This small thrust places inverted

Greyson Shale on an inverted section of Flathead Sandstone, Wolsey Shale, and Meagher Limestone. This fault probably formed while the section was being inverted, the initial movement occurring along the Greyson-Flathead contact. Minimum stratigraphic separation is 350 feet.

On the western side of Hogback Mountain, in the upper Paleozoic section, there is a N.15° W.-trending thrust fault which dips about 40° to the west. The stratigraphic separation on this fault is about 100 feet.

Folds

In the Hogback Mountain area, thrust plates A, C, E, and F (Fig. 3), consisting mostly of Belt strata, show only minor folding. Thrust plate B is strongly folded, and is made up of inverted strata (Figs. 4 and 5) ranging in age from Precambrian to Pennsylvanian. Intense folding is shown in thrust plate D, which is made up mostly of Devonian and Mississippian rocks.

North- to northwest-trending gentle folds occur in thrust plate E. These folds consist of open, upright anticlines and synclines with small amplitudes. In thrust plate C there is a very broad northwest-trending syncline with a minimum amplitude of 400 feet.

Thrust plate D has been deformed into a major overturned anticline; subsequent erosion has exposed this plate as a half-fenster (Fig. 3). The thrust plate D anticline, herein named the Hogback Mountain anticline (Fig. 7), trends N.55° W., parallel to the trend of the faults bounding thrust plate D. The exposed part of the Hogback Mountain anticline averages about 2½ miles in width and is made up primarily of intensely deformed limestone of the Madison Group. The exposed part of the core consists of the Three Forks Formation and Jefferson Dolomite. The northeast limb of the Hogback Mountain anticline has dips which are very steep to vertical and overturned. The southwest limb has gentle to moderate dips, except where some of the beds have been overturned by drag adjacent to the Scout Camp thrust (Pl. 2, cross sections D-D' and F-F'). The amplitude of the Hogback Mountain anticline is probably one to two miles.

Recumbent folding within and near the crest of the Hogback Mountain anticline has produced some curious outcrop patterns on Hogback Mountain. Note the "hook" in the Three Forks Formation on the north side of Hogback Mountain and the irregular Lodgepole-Mission Canyon contact (Pl. 1; Pl. 2, cross sections C-C' and D-D').

There are many intricately contorted beds within the Hogback Mountain anticline; only the largest are shown on the geologic map. Limestone of the Madison Group shows the most

Fig. 7.--Hogback Mountain anticline viewed northwest from east rim of Trout Creek Canyon.

intense deformation. A spectacular, yet representative, example may be seen in sec. 33, T.13N., R.1W., on the side of a small east-west ridge a few hundred feet south of Beaver Creek (Pl. 2, cross section B-B').

At several places along the southwest limb of the Hogback Mountain anticline, strata have been deformed into overturned synclines by drag along the Scout Camp thrust. Along Trout Creek, a sheet of Lodgepole Limestone has been folded into an overturned syncline, and thrust to the northeast over Mission Canyon Limestone (Pl. 2, cross section F-F'). Along Soup Creek, a small plate of Pilgrim Limestone and Jefferson Dolomite has been deformed into an overturned syncline, and thrust to the northeast over Jefferson Dolomite (Fig. 8). Just north of Soup Creek the Pilgrim Limestone and Jefferson Dolomite form a northnorthwest-trending anticline and steeply overturned syncline; farther north, the anticline is also overturned (Pl. 2, cross section D-D'). The amplitudes of these folds are several thousand feet. Between Checkerboard Gulch and Sheep Gulch, on the west side of Hogback Mountain, the Jefferson Dolomite, Three Forks Formation, and Lodgepole Limestone form a north-trending overturned syncline with an amplitude of about 1,000 feet (Pl. 2, cross section C-C').

Thrust plate B consists of strongly folded, inverted strata. The plate resembles a N.55° W.-trending upper limb

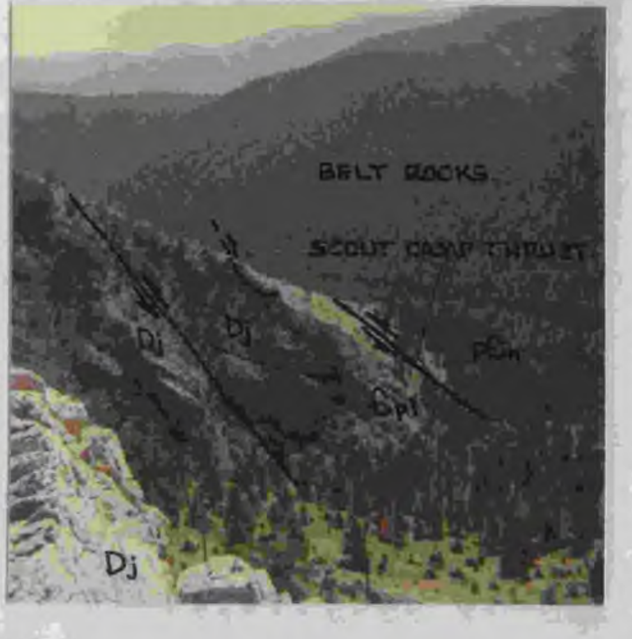


Fig. 8.--Pilgrim Limestone and Jefferson Dolomite overturned by drag along the Scout Camp fault and thrust over Jefferson Dolomite.

of a recumbent syncline, with considerable internal deformation. The Meagher Limestone, in particular, shows some rather complex folding; just south of Beaver Creek, the Meagher and adjacent units have been tightly folded into a series of northeast-trending antiforms and synforms with amplitudes of several hundred feet (Fig. 6). North of Beaver Creek, the Meagher has been complexly folded into a tight, northwest-trending antiform-synform pair. The Madison, in thrust plate B along Beaver Creek, forms a northwest-trending, overturned chevron fold with an amplitude of about 1,000 feet (Fig. 5; Pl. 2, cross section B-B'). In the eastern part of thrust plate B, the nose of an antiform plunges southwest toward the Scout Camp thrust, resulting in some intense deformation in the Meagher Limestone and adjacent units (Pl. 2, cross section E-E').

Discussion

Folds in the Hogback Mountain quadrangle and surrounding area (Fig. 3) have a general northwest trend, implying northeast-southwest compression. Most of the axial planes dip to the southwest indicating yielding to the northeast. Thrusts in the area also show yielding to the northeast.

The Madison Group is abnormally thick in the map-area. Robinson (1959) suggested that the Madison Group acted as a buttress during Laramide folding. If so, this buttressing, or piling-up effect is responsible for the tremendous apparent thickness of the Madison Group in thrust plate D (Fig. 9), and to a lesser extent, in thrust plate B.

The first thrust to form in the map-area was the Scout Camp thrust. This is not apparent from the geologic map of the Hogback Mountain area, but mapping in the Nelson 7½-minute quadrangle to the west (W. B. Myers and M. E. McCallum, oral commun., 1971; Fig. 3) has shown the Moors Mountain thrust to

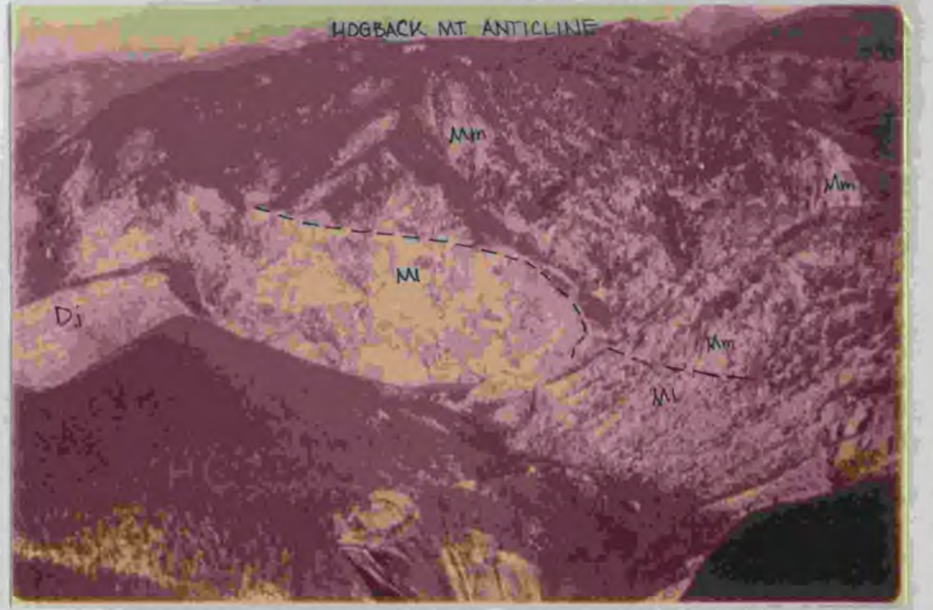


Fig. 9.--Section through Hogback Mountain anticline along Beaver Creek, showing buttressing effect and abnormal thickness of Mission Canyon Limestone. View to the northwest.

truncate the Scout Camp thrust. Later, the Scout Camp thrust was intensely folded and overturned (Figs. 4 and 5).

Sometime during the folding of the Scout Camp thrust, movement began on the Moors Mountain thrust to the west. This thrust overrides and truncates the Scout Camp thrust and therefore is younger. The folding episode which deformed the Scout Camp thrust was still acting on the area during formation of the Moors Mountain thrust for it also is folded, though not nearly as intensely.

The Jim Ball Basin thrust is believed to be correlative with the Moors Mountain thrust, although the evidence is by no means conclusive. Like the Moors Mountain thrust, the Jim Ball Basin thrust appears to be only slightly folded. Also, in the southeast corner of thrust plate C there are some thin layers of limestone in the Greyson Shale which are unlike anything exposed in the Greyson in thrust plate E. Therefore, it is believed that thrust plate C is correlative with thrust plates A and F and not with thrust plate E. Another possibility is that the Jim Ball Basin thrust is a later, less folded split from the Scout Camp thrust (W. B. Myers, written commun., 1971; Fig. 10 D).

Diagrammatic sections showing the structural development of the Hogback Mountain area and the relationship between the Scout Camp, Moors Mountain, and Jim Ball Basin thrusts are given in Figure 10.

Displacement on the Scout Camp thrust is believed to be at least five miles; on the Moors Mountain thrust it is probably more than eight miles. In the map-area, thrust displacements are considerably greater than the stratigraphic separation because the upper thrust plates are relatively

A. Development of Scout Camp thrust from lateral compressive forces from the southwest. May have been proceded by minor folding. Upper plate gently deformed, lower plate strongly deformed.

B. Development of Moors Mountain thrust, preceded by significant folding of Scout Camp thrust.

C. Folding, complex refolding, and overturning of Scout Camp thrust. Folding of Moors Mountain thrust. Showing present land surface after Cenozoic uplift and erosion.

D. ALTERNATIVE INTERPRETATION: The Jim Ball Basin thrust is a less folded branch of the intensely folded and overturned Scout Camp thrust.

Fig. 10.--Structural development of major Laramide tectonic features in the Hogback Mountain area. This figure is along the same line of cross section as E-E', Pl. 1.

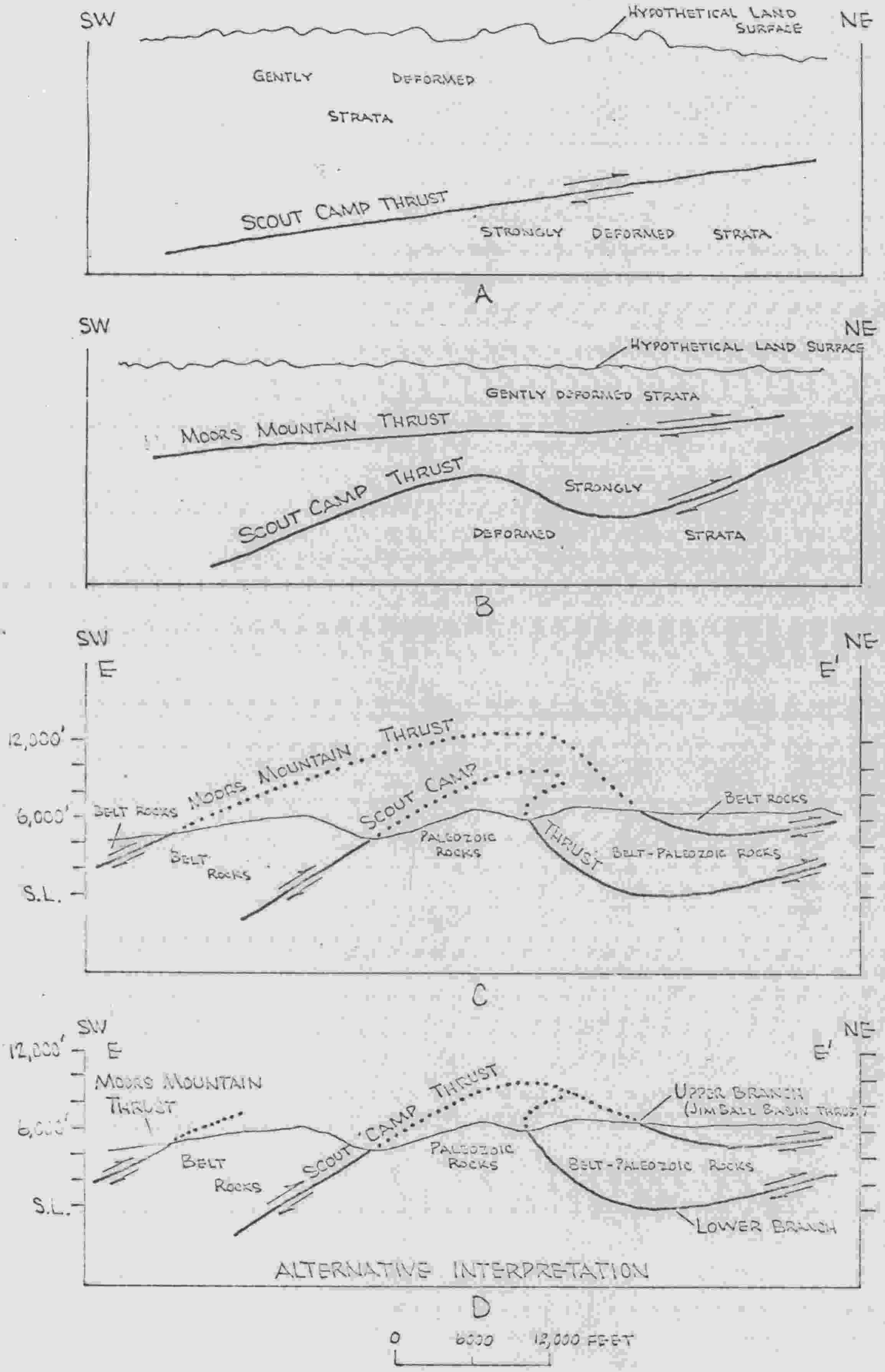


Fig. 10.--Continued

undeformed (unless overridden by younger thrusts), and the dip angle on the faults is usually low. Since the minimum stratigraphic separation on the Scout Camp thrust is 2½ miles, the thrust displacement is estimated to be at least 5 miles. Estimating displacement on the Moors Mountain thrust is more hazardous. If the Jim Ball Basin thrust is correlative with the Moors Mountain thrust (a reasonable assumption) the minimum thrust displacement is about eight miles. In addition to thrusting, there is considerable amount of crustal shortening due to Laramide folding. A very rough minimum estimate of crustal shortening due to thrusting and folding in the Hogback Mountain area is fifteen miles. As for a maximum figure, Lochman and Duncan (1944) estimate at least fifty miles of northeasterly, post-Cambrian crustal shortening in southwestern Montana.

Southwest-dipping thrusts and northwest-trending major folds indicate northeast-southwest directed compressive forces in the Hogback Mountain area. Birkholz (1967) has postulated that compressive forces from the west, acting on Belt strata near the cratonic buttress at the northern boundary of the Central Montana trough, produced northwest-trending thrusts with a large component of strike-slip movement. No strike-slip was noted on any of the thrusts in the Hogback Mountain area, and as can be seen in Figure 2, the northwest-trending thrusts in the northern Big Belt Mountains continue northwestward, well past the Central Montana trough without any appreciable change in strike.

However, Birkholz was correct in stating that Disturbed Belt structures in this area are related to the eastern limit of Belt strata and the configuration of the Central Montana trough. One effect is a considerable widening of the Disturbed Belt to the east, conforming to the eastward-trending zero isopach of Belt rocks at the northern margin of the Central Montana trough (Fig. 2). Another effect appears to be a splitting of Disturbed Belt thrusts, one zone with a southeast trend, the other zone bending to the south and cutting across the axis of the Central Montana trough (Fig. 2). The Hogback Mountain area lies within the southeast-trending zone of thrusts.

The great thrusts marking the western limit of the Disturbed Belt in Montana are probably decollement structures (Gilluly, 1965), but speculations concerning the origin of Laramide forces producing these features is beyond the scope of this paper. However, some regional aspects have been noted which must be explained when considering the evolution of the Disturbed Belt. First, the intensity of folding decreases to the west (Robinson and others, 1968). Just east of the Boulder

Batholith the major folds are open and upright (Klepper and others, 1957), while to the east in the Hogback Mountain area the major folds are overturned to the northeast and complexly refolded.

Second, the thrusts are younger to the west in the Hogback Mountain area because the Scout Camp thrust is truncated and overridden by the Moors Mountain thrust (Fig. 3). This trend holds regionally because the Eldorado thrust, the westernmost element of the Disturbed Belt in this area, is less intensely folded than the Moors Mountain thrust, and therefore is younger (Robinson, 1968).

Two other interesting features of the Disturbed Belt are the interrelationship between plutonism, volcanism, and tectonism pointed out by Robinson and others (1968), and the shallow-seated nature of the deformation insofar as no crystalline basement rocks are involved in thrusting.

Post-Laramide Structure

Post-Laramide deformation in the Hogback Mountain area is limited to regional uplift with accompanying high-angle faulting and gentle northwestward tilting.

There are two steep faults in the map-area; one bounds the southern margin of thrust plate C, and the other is located in the extreme southwest corner of the quadrangle. Traces of both faults are covered with surface debris and were not observed; their presence is inferred mainly from topography. The fault in the southwest corner strikes N.48° W., and is down to the southwest, with Greyson Shale against Greyson. Relief on the fault scarp suggests about 1,000 feet of stratigraphic separation.

The steep fault at the southern margin of thrust plate C trends N.78° W., with the southern block, consisting of inverted Mission Canyon Limestone, being upthrown relative to the northern block of Greyson Shale. Stratigraphic separation is about 3,000 feet where the fault leaves the map-area on the east. Displacement decreases to the west and probably dies out in Indian Flats.

High-angle faulting in the map-area is probably directly related to Cenozoic uplift of the Big Belt Mountains, a process which is still continuing (Pardee, 1926). Evidence in the Hogback Mountain area substantiating continued uplift includes deep, narrow gullies cut into older fill material, streams not in equilibrium with their beds or channels, large deltas being formed at the mouths of many small intermittent streams, and the fact that v-shaped valley walls steepen with depth.

Northwestward tilting accompanying regional uplift is responsible for the plunge on the folded thrusts at the northern end of the Big Belt Mountains, a fact which is not readily apparent in the Hogback Mountain area but which can be easily seen by the fault traces in Figure 3. This northwest tilting has produced sinuous traces on the Scout Camp and Moors Mountain thrusts, and is responsible for the half-fenster (thrust plate D) and inverted half-klippe (thrust plate B) of the Scout Camp thrust. Tilting has also left behind thrust plate C as a klippe trapped in the Candle Mountain syncline.

TECTONIC HISTORY

Decipherable structural development of the Hogback Mountain area began with the formation of the Beltian geosyncline and the east-projecting Central Montana trough. During Precambrian time these negative areas accumulated tremendous thicknesses of dominantly fine-grained clastic sediments of the Belt Series. The southern margin of the Central Montana trough was controlled by faulting which locally exerted a powerful influence on Belt deposition; in the Hogback Mountain area this effect is almost negligible.

During late Precambrian or Early Cambrian time Belt strata in the Central Montana trough were broadly uplifted and eroded to a surface of low relief. The Hogback Mountain area appears to have been tectonically quiet from Middle Cambrian to Late Cretaceous time. Regionally, to the east, the Central Montana trough was strongly negative during Late Mississippian time.

Most of the structure in the Hogback Mountain area formed in response to northeast-southwest compression during the last 20 m.y. of the Cretaceous. Large-scale thrusting occurred first, with the Scout Camp thrust being the first to form, although minor folding may have preceded this event.

Soon after movement began on the Scout Camp thrust, movement on the Moors Mountain thrust was initiated, but not before the Scout Camp thrust was significantly folded. Continued folding resulted in overturning of the Scout Camp thrust and folding of the Moors Mountain thrust. Thus, the rocks below the Moors Mountain thrust form a major northwest-trending overturned anticline-syncline, while the upper plate has been less intensely deformed into a northwest-trending anticline-syncline (Figs. 3 and 10C).

Intrusive bodies in the map-area were emplaced before culmination of Laramide folding but the exact relationship between thrusting, folding, and plutonism is unknown.

Post-Laramide deformation in the Hogback Mountain area is limited to Cenozoic uplift with accompanying gentle northwestward tilting and minor high-angle faulting.

REFERENCES CITED

Barnett, V. H., 1917, Geology of the Hound Creek district of the Great Falls coal field, Cascade County, Montana: U. S. Geol. Survey Bull. 641-H, p. 215-231.

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

Birkholz, D. O., 1967, Geology of the Camas Creek area, Meagher County, Montana: unpub. M.S. thesis, Montana College Mineral Sci. and Technology, Butte, 68 p.

Collier, A. J., and Cathcart, S. H., 1922, Possibility of finding oil in laccolithic domes south of the Little Rocky Mountains, Montana: U. S. Geol. Survey Prof. Paper 120-F, p. 111-121.

Darton, N. H., 1904, Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain front range: Geol. Soc. America Bull., v. 15, p. 379-448.

Deiss, C. F., 1936, Revision of type Cambrian formations and sections of Montana and Yellowstone Park: Geol. Soc. America Bull., v. 47, no. 8, p. 1257-1342.

Emmons, W. H., and Calkins, F. C., 1913, Geology and ore deposits of Phillipsburg Quadrangle, Montana: U. S. Geol. Survey Prof. Paper 78, 271 p.

Freeman, V. L., Ruppel, E. T., and Klepper, M. R., 1958, Geology of part of the Townsend Valley, Broadwater and Jefferson Counties, Montana: U. S. Geol. Survey Bull. 1042-N, p. 481-556.

Gilluly, James, 1965, Volcanism, tectonism, and plutonism in the western United States: Geol. Soc. America Spec. Paper 80, 69 p.

Grant, R. E. 1965, Faunas and stratigraphy of the Snowy Range Formation (upper Cambrian) in southwestern Montana and northwestern Wyoming: Geol. Soc. America Mem. 96.

Gutshick, R. C., Suttner, L. J., and Switer, M. H., 1962, Biostratigraphy of transitional Devonian-Mississippian Sappington Formation of southwest Montana _in_ Guidebook of the Devonian System of Montana and Adjacent Areas: Billings Geol. Soc. 13th Field Conf., p. 79-89.

Haynes, W. P., 1916, The Lombard overthrust and related geological features: Jour. Geology, v. 24, p. 269-290.

Hruska, D. C., 1967, Geology of the Dry Range area, Meagher County, Montana: unpub. M.S. thesis, Montana College Mineral Sci. and Technology, Butte, 89 p.

Kelley, V. C., 1956, Thickness of strata: Jour. Sedimentary Petrology, v. 26, no. 4, p. 289-300.

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

Knechtel, M. M., Smedley, J. E., and Ross, R. J., Jr., 1954, Little Chief Canyon Member of Lodgepole Limestone of Early Mississippian age in Montana: Am. Assoc. Petroleum Geol. Bull., v. 38, no. 11, p. 2395-2400.

Knopf, A., 1963, Geology of the northern part of the Boulder Batholith and adjacent area, Montana: U. S. Geol. Survey Misc. Geologic Inv. Map I-381.

Lochman, Christina, 1950, Status of Dry Creek shale of Central Montana: Am. Assoc. Petroleum Geol. Bull., v. 34, no. 11, p. 2200-2222.

Lochman, C., and Duncan, D., 1944, Early Upper Cambrian faunas of Central Montana: Geol. Soc. America Spec. Paper 54, 181 p.

Lorenz, H. W., 1962, Geologic road log, Helena to Beaver Creek in Guidebook of the Devonian System of Montana and Adjacent Areas: Billings Geol. Soc. 13th Field Conf., p. 138-142.

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

Maughan, E., and Roberts, A. E., 1967, Big Snowy and Amsden Groups and the Mississippian-Pennsylvanian boundary in Montana: U. S. Geol. Survey Prof. Paper 554-B, 27 p.

McMannis, W. J., 1963, LaHood Formation--A coarse facies of the Belt Series in southwestern Montana: Geol. Soc. America Bull., v. 74, no. 4, p. 407-436.

Mertie, J. B., Fischer, R. P., and Hobbs, W., 1951, Geology of the Canyon Ferry Quadrangle, Montana: U. S. Geol. Survey Bull. 972, 95 p.

Nelson, W. H., 1963, Geology of the Duck Creek Pass Quadrangle, Montana: U. S. Geol. Survey Bull. 1121-J, 56 p.

Obradovich, J. D., and Peterman, F. E., 1968, Geochronology of the Belt Series, Montana: Canadian Jour. Earth Sciences, v. 5, p. 737-747.

Pardee, J. T., 1926, The Montana earthquake of June 27, 1925: U. S. Geol. Survey Prof. Paper 147, p. 7-23.

Pardee, J. T., and Schrader, F. C., 1933, Metalliferous deposits of the greater Helena mining region, Montana: U. S. Geol. Survey Bull. 842, 318 p.

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

Robinson, G. D., 1959, The Disturbed Belt in the Sixteen Mile area, Montana in Guidebook of the Sawtooth-Disturbed Belt area: Billings Geol. Soc. 10th Field Conf., p. 34-40.

Robinson, G. D., Klepper, M. R., and Obradovich, J. D., 1968, Overlapping plutonism, volcanism, and tectonism in the Boulder Batholith region, western Montana: Geol. Soc. America Mem. 116, p. 557-576.

Robinson, G. D., McCallum, M. E., and Hays, W. H., 1969, Geologic map of the Upper Holter Lake Quadrangle, Lewis and Clark County, Montana: U. S. Geol. Survey Geologic Quadrangle Map GQ-840.

Sandberg, C. A., and Hammond, C. R., 1958, Devonian System in Williston Basin and Central Montana: Am. Assoc. Petroleum Geologist Bull., v. 42, no. 10, p. 2293-2334.

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

Sloss, L. L., 1950, Paleozoic sedimention in Montana: Am. Assoc. Petroleum Geol. Bull., v. 34, no. 3, p. 423-451.

Sloss, L. L., and Laird, W. M., 1947, Devonian system in central and northwestern Montana: Am. Assoc. Petroleum Geol. Bull., v. 31, no. 8, 1404-1430.

Walcott, C. D., 1899, Precambrian fossiliferous formations: Geol. Soc. America Bull., v. 10, p. 199-244.

Weed, W. H., 1892, Two Montana coal fields: Geol. Soc. America Bull., v. 3, p. 301-330.

Weed, W. H., 1896, Yellowstone National Park Folio: U. S. Geol. Survey Geologic Atlas, Folio 30, 18 p.

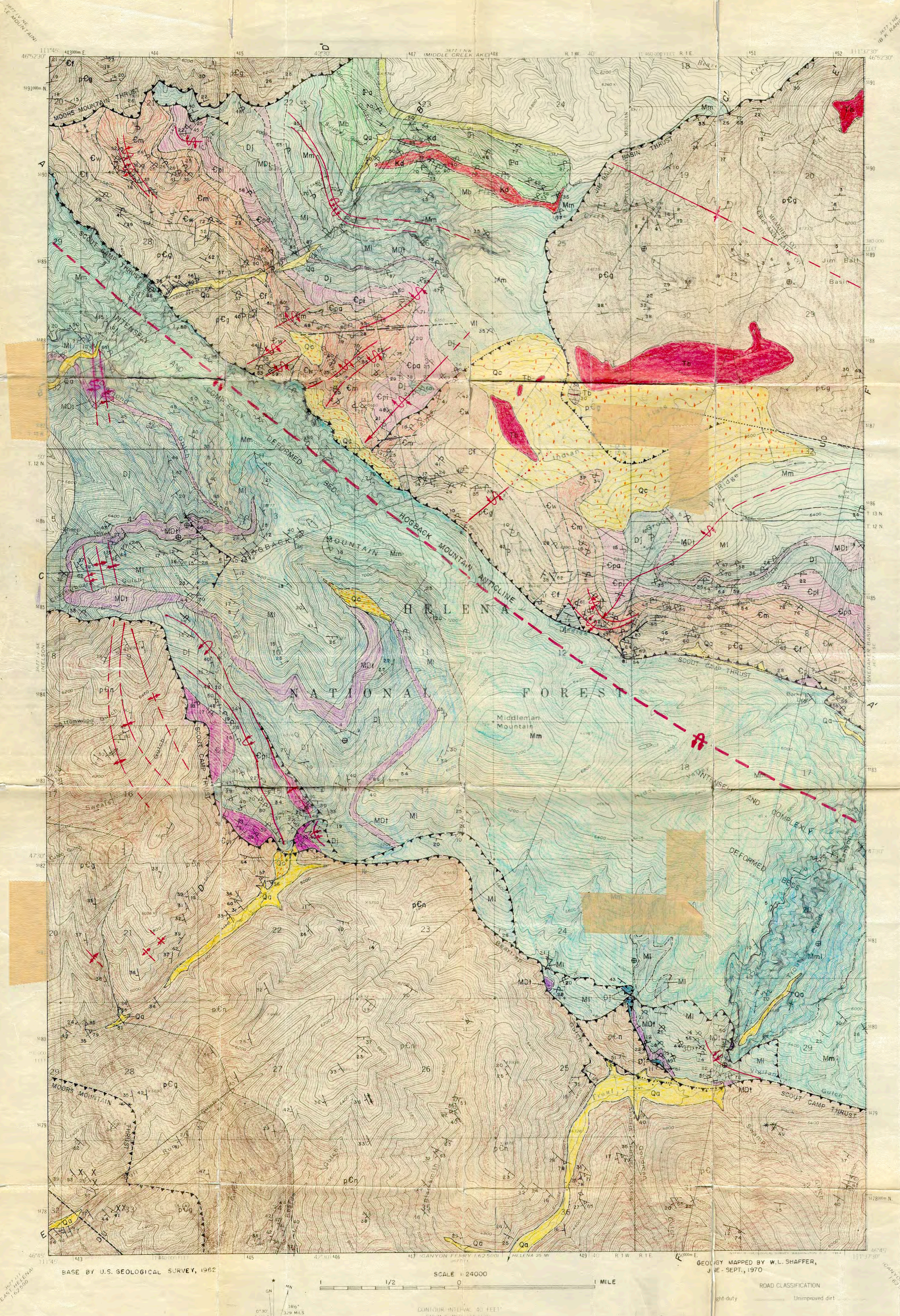
Weed, W. H., 1899a, Fort Benton Folio, Montana: U. S. Geol. Survey Geologic Atlas, Folio 55.

Weed, W. H., 1899b, Little Belt Mountains Folio, Montana: U. S. Geol. Survey Geologic Atlas, Folio 56, 15 p.

Weinberg, D. M., 1970, Structural geology of the Beaver Creek area, Big Belt Mountains, Montana: unpub. M.S. thesis, Univ. New Mexico, Albuquerque, 49 p.

Wengerd, S. A., 1948, Fernvale and Viola limestones of south-central Oklahoma: Am. Assoc. Petroleum Geol. Bull., v. 32, no. 12, p. 2183-2253.

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



BASE BY U.S. GEOLOGICAL SURVEY, 1962

GEOLOGY MAPPED BY W.L. SHAFFER,
JUNE-SEPT., 1970

SCALE 1:24000

1 1/2 0 1 MILE

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

Light-duty Unimproved dirt

MONTANA

QUADRANGLE LOCATION

PLATE I. GEOLOGIC MAP OF THE HOGBACK MOUNTAIN AREA, NORTHERN BIG BELT MOUNTAINS, MONTANA

EXPLANATION

QUATERNARY

Qa 735

ALLUVIUM
Clay, silt, and poorly sorted subrounded to angular sand and gravel; fluvial; 0-50(?) feet thick

Qc

COLLUVIUM
Slope wash, landslide debris, and talus; 0-25(?) feet thick

INTERMITTENT REGIONAL UPLIFT, CONTINUING TO PRESENT

TERTIARY

Tb 745

BASALT

MAJOR UNCONFORMITY, REGIONAL THRUST FAULTING AND FOLDING

CRETACEOUS (?)

Kd 744

DIORITE

SMALL DIKES AND SILLS

PENNSYLVANIAN

IPq Δ to Cq

QUADRANT FORMATION
White to light-gray, thick-bedded, fine- to medium-grained quartzitic sandstone, weathers white to pale-orange; forms ledges; 250-300 feet thick

IPa

AMSDEN FORMATION
Yellow-red mudstone, siltstone, and fine-grained, calcareous sandstone grading upward into gray-brown limestone and subordinate varicolored shale and quartzitic sandstone; 450 feet thick

REGIONAL DISCONFORMITY

MISSISSIPPIAN

Mb 751

BIG SNOWY GROUP
Highly varied lithology; mainly varicolored shale, and impure limestone with subordinate sandstone; poorly exposed; 900-1,100 feet thick

REGIONAL DISCONFORMITY

Mml ✓

MADISON GROUP
Undivided in areas of intense internal deformation

✓ Mm 737½

MISSION CANYON LIMESTONE
Gray-brown, densely crystalline, thick-bedded to massive and indistinctly bedded, slightly fossiliferous and petroliferous limestone; weathers light-gray; forms cliffs; 1,200-1,400 feet thick

✓ Ml 750

LODGEPOLE LIMESTONE
Gray-brown, densely crystalline, thin- to medium-bedded, distinctly bedded, very fossiliferous, slightly petroliferous limestone; weathers yellow-gray to brown-gray; may include as much as 15 feet black shale at base; forms ledges; 800 feet thick

DEVONIAN

✓ MDt 742

THREE FORKS FORMATION
Varied lithology; lower part mainly varicolored shale with subordinate limestone, siltstone, and mudstone; upper part orange, flaggy, calcareous siltstone and very fine-grained sandstone; very fossiliferous; poorly exposed; 150-250 feet thick

Dj 741½

JEFFERSON DOLOMITE
Brown to gray-brown, finely to coarsely crystalline, thin- to thick-bedded dolomite; highly fetid and petroliferous; weathers brown-gray with a sugary or felted surface; light brown-gray, dolomitic limestone, 60-80 feet thick at top; forms ledges and cliffs; 600-700 feet thick

REGIONAL DISCONFORMITY

CAMBRIAN

€pi Δ to €pl

PILGRIM LIMESTONE
Dark-brown to dark-gray, thin- to thick-bedded, densely crystalline limestone; weathers yellow-gray; abundant intraformational conglomerate; forms ledges; 150-300 feet thick

€pa 745½ Δ to €p

PARK SHALE
Green-gray and brown-maroon, laminated, slightly micaceous shale; poorly exposed; 100-250 feet thick

€m 737

MEAGHER LIMESTONE
Dark-brown to dark-gray, thin- to thick-bedded, unevenly bedded, densely crystalline, orange-mottled limestone; weathers light-gray to light brown-gray; forms ledges and cliffs; 200-400 feet thick

€w

WOLSEY SHALE
Olive to green-gray and brown, wavy-bedded, silty, highly micaceous shale; subordinate limestone and quartzitic sandstone; poorly exposed; 300-350 feet thick

€f

FLATHEAD SANDSTONE
Light-pink to tan, thin- to thick-bedded and cross-bedded, poorly sorted, medium- to coarse-grained, subrounded, slightly conglomeratic quartzitic sandstone; forms ledges; 150-250 feet thick

ANGULAR UNCONFORMITY

PRECAMBRIAN

Belt Supergroup

p€g 736

GREYSON SHALE
Dark-gray, brown, yellow-brown, and gray-green, laminated, slightly calcareous shale, argillite, and siltstone; subordinate light-brown, very fine- to fine-grained quartzitic sandstone, and dark-gray to black, densely crystalline limestone; 5,300 feet thick

p€n 744

NEWLAND LIMESTONE
Yellow-brown, red-brown, and gray to black, calcareous argillite and silty shale; dark-gray, densely crystalline, slightly dolomitic limestone; subordinate siltstone and very fine-grained quartzitic sandstone; a few thin layers of coarse-grained sandstone at top; 5,500 feet exposed; base cut out by thrust fault

SYMBOLS

Long dashed where approximately located; short dashed where inferred; dotted where concealed

CONTACT

STEEP FAULT
U, upthrown side; D, downthrown side; arrows show relative movement

THRUST FAULT
Sawteeth on upper plate. In sections, arrows show relative movement

OVERTURNED THRUST FAULT
Sawteeth rooted on upper plate, point in direction of dip

ANTICLINE
Showing axial trace and direction of plunge

SYNCLINE
Showing axial trace and direction of plunge

OVERTURNED ANTICLINE
Showing axial trace, direction of plunge, and direction of dip of limbs

OVERTURNED SYNCLINE
Showing axial trace, direction of plunge, and direction of dip of limbs

ANTIFORM
Showing axial trace, direction of plunge, and direction of dip of limbs

SYNFORM
Showing axial trace, direction of plunge, and direction of dip of limbs

35 Inclined Vertical Horizontal 80 Overturned
STRIKE AND DIP OF BEDS

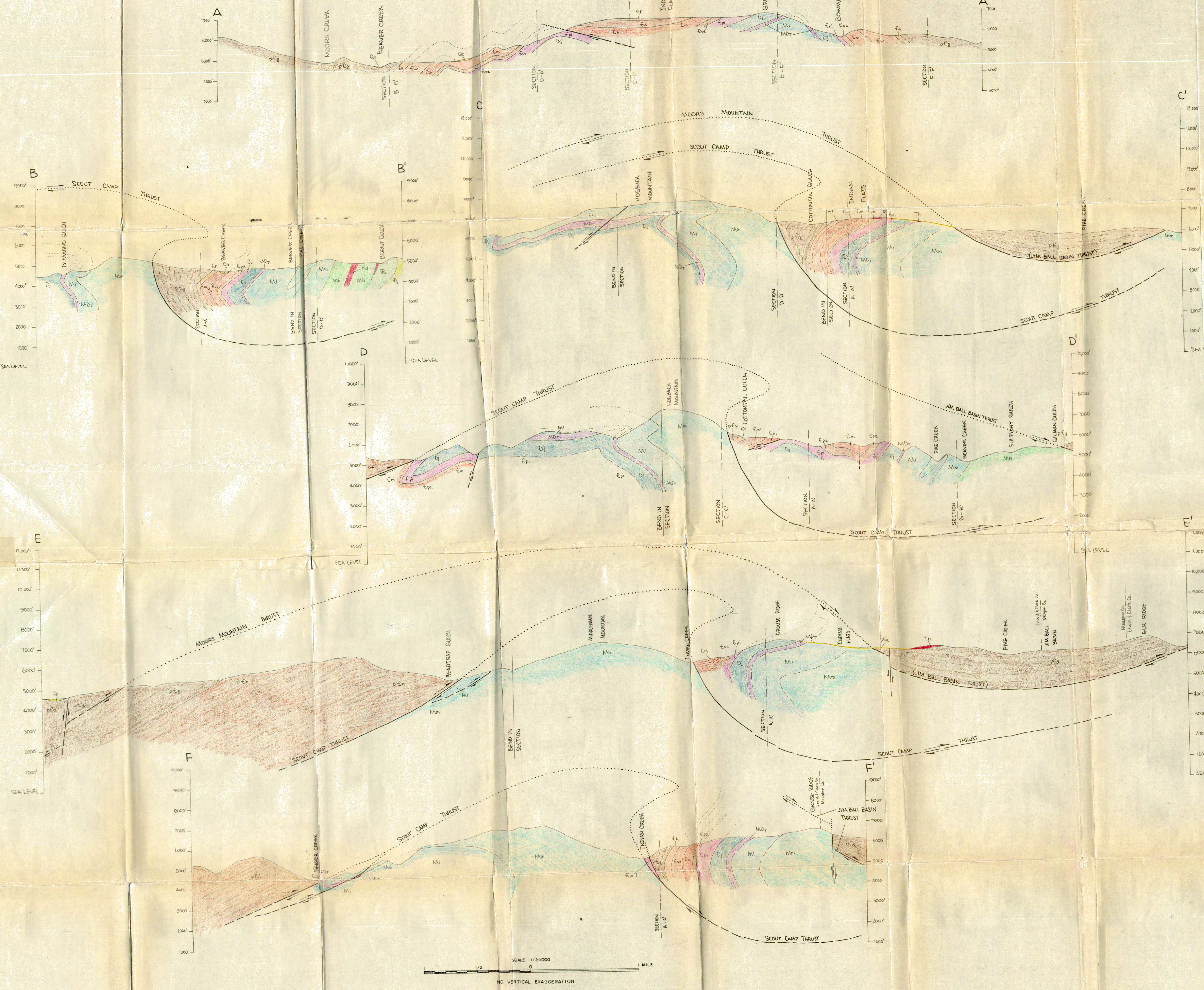
30
CONTORTED BEDS
Showing average strike and dip

25 Inclined Vertical
STRIKE AND DIP OF CLEAVAGE

STRUCTURAL FORM LINES
Added to sections where needed to show significant detail

X
PROSPECT PIT

ADIT PORTAL
Showing direction of drift



NO VERTICAL EXAGGERATION

FOR EXPLANATION SEE PLATE 1

PLATE 2. GEOLOGIC STRUCTURE SECTIONS OF THE HOGBACK MOUNTAIN AREA