



Geology of the Southwestern Horseshoe Hills area, Gallatin County, Montana
by Ronald Arthur Spahn

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE IN APPLIED SCIENCE With a Major in Geology
Montana State University
© Copyright by Ronald Arthur Spahn (1967)

Abstract:

The oldest rocks of this 70 square mile area located at the northern edge of the Three Forks Basin are the arkosic slightly metamorphosed Precambrian sedimentary rocks which were derived from a nearby fault uplift to the south. Basement rocks beneath the 4700+ foot thick sequence are not exposed. Precambrian rocks are overlain unconformably by a primarily marine 8000 foot marginal geosynclinal sedimentary sequence. All systems except the Ordovician, Silurian, and Triassic systems are present. Scattered patches of a diversity of continental rock types represent the Cenozoic.

Deformation and erosion beginning in the latest Precambrian extended into the Early Cambrian. A major orogeny (the Laramide) began in the Late Cretaceous and continued into the early Tertiary. In the map area - this deformation began as folding and faulting and culminated in thrust faulting. Post-Laramide tensional faulting resulted from the relaxation of compressional forces. The northeast-trending structural features are the product of the juncture of two regional structural elements; the Montana Disturbed Belt and the northern edge of the Wyoming Shelf.

The three lithologically similar sill zones present indicate intrusion preceding deformation.

The mature landscape is the product of exhumation and dissection with continued fault movement.

GEOLOGY OF THE SOUTHWESTERN HORSESHOE HILLS AREA,
GALLATIN COUNTY, MONTANA

by

RONALD ARTHUR SPAHN, JR.

A thesis submitted to the Graduate Faculty in partial
fulfillment of the requirements for the degree

of

MASTER OF SCIENCE IN APPLIED SCIENCE

With a Major in Geology

Approved:

Milton J. Edie
Head, Major Department

William J. McManis
Chairman, Examining Committee

AJ Goering
Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

December, 1967

ACKNOWLEDGMENTS

Sincere appreciation is extended to the many individuals who made this study possible. Particular thanks are due to Dr. William J. McMannis for editorial aid, field guidance, and generous access to his personal library. Thanks are also extended to Dr. John Montagne and Dr. Robert Chadwick for assistance with problems in their fields, and to Dr. Charles Bradley for critical advice and an airplane tour of the area. The encouragement and financial assistance of my parents is gratefully acknowledged. Appreciation is extended to the Department of Earth Science for material assistance, and the many landowners of the area who granted access to their land.

TABLE OF CONTENTS

	Page
INTRODUCTION.	1
Location and Physiography	2
Natural Setting	3
Land Use	5
Access	5
Previous Investigations	6
Objectives	6
STRATIGRAPHY.	7
Precambrian.	7
LaHood Formation	7
Cambrian	9
Flathead Formation	9
Wolsey Shale	11
Meagher Limestone	12
Park Shale	14
Pilgrim Limestone	15
Cambrian and Devonian.	16
Snowy Range Formation	17
Cambro-Devonian Unconformity	20
Maywood Formation	21
Devonian	23
Jefferson Dolomite	23
Three Forks Formation	25
Sappington Formation	28
Permo-Carboniferous.	31
Lodgepole Limestone	32
Mission Canyon Limestone	33
Amsden Formation	36
Quadrant Formation	38
Phosphoria Formation	39
Triassic	42
Jurassic	43
Sawtooth Formation	43
Rierdon Formation	44
Swift Formation	45
Morrison Formation	45
Cretaceous.	47
Kootenai Formation	47
Colorado Group	48

	Page
Post-Laramide Deposits	50
High-level Gravel	50
Tuffaceous Beds	51
Travertine	53
Cemented Gravel	55
Loess	57
Older Alluvium	58
Recent Alluvium	59
GEOMORPHOLOGY	60
IGNEOUS GEOLOGY	62
STRUCTURE	66
Tectonic Setting	66
Local Structure	69
Introduction	69
Green Thrust Section	69
Cottonwood Section	73
Intrusives of the Cottonwood Section	75
Central Folded Section	77
East Gallatin Section	78
Summary of Structural History	80
ECONOMIC GEOLOGY	82
APPENDIX	86
REFERENCES CITED	89

LIST OF PLATES

Plate I	Geologic Map and Cross-sections of the South-western Horseshoe Hills Area.	In pocket
---------	--	-----------

LIST OF FIGURES

		Page
Figure 1	Index Map	2
Figure 2	Central Folded Section, looking north	4
Figure 3	Snowy Range - Maywood Stratigraphic Relationships . . .	18
Figure 4	Schematic nomenclatural correlation chart: Three Forks Sappington interval	27
Figure 5	Index map showing structural divisions.	70

ABSTRACT

The oldest rocks of this 70 square mile area located at the northern edge of the Three Forks Basin are the arkosic slightly metamorphosed Precambrian sedimentary rocks which were derived from a nearby fault uplift to the south. Basement rocks beneath the 4700+ foot thick sequence are not exposed. Precambrian rocks are overlain unconformably by a primarily marine 8000 foot marginal geosynclinal sedimentary sequence. All systems except the Ordovician, Silurian, and Triassic systems are present. Scattered patches of a diversity of continental rock types represent the Cenozoic.

Deformation and erosion beginning in the latest Precambrian extended into the Early Cambrian. A major orogeny (the Laramide) began in the Late Cretaceous and continued into the early Tertiary. In the map area this deformation began as folding and faulting and culminated in thrust faulting. Post-Laramide tensional faulting resulted from the relaxation of compressional forces. The northeast-trending structural features are the product of the juncture of two regional structural elements: the Montana Disturbed Belt and the northern edge of the Wyoming Shelf.

The three lithologically similar sill zones present indicate intrusion preceding deformation.

The mature landscape is the product of exhumation and dissection with continued fault movement.

INTRODUCTION

The Horseshoe Hills are a sparsely-populated, semi-arid area of moderate relief at the head of the Missouri River in southwestern Montana. The rugged mountains and broad basins of this part of the state are the site of much agricultural and mineral wealth. Geologically, the area contains an intricately folded and faulted Precambrian through Mesozoic sedimentary sequence with minor igneous intrusives and gently-dipping Cenozoic sediments.

Location and Physiography

The study area encompasses the southern two-thirds of the north half of the Manhattan Quadrangle, which is bounded by the $111^{\circ}30'$ meridians and the $45^{\circ}52'30''$ and 46° parallels. The mapped area is bounded on the south by the $45^{\circ}52'30''$ parallel, on the west by the Missouri River floodplain and quadrangle boundary, on the north by the northern edge of Township 2 North, and on the east by the quadrangle boundary (Figure 1 and Plate I). The nearest large town is Bozeman, located 25 miles to the southeast. The mapped portion of the quadrangle encompasses an area of approximately 60 square miles.

The Horseshoe Hills are a part of the Three Forks District of the Northern Rocky Mountain Province of Fenneman (1931, p. 183-224). Elevation in the map area ranges from 4,030 feet near the Missouri River to 6,044 feet near the northern boundary. Topographic features consist principally of un-forested, winding hogback ridges locally incised by streams. Peripheral gently rolling uplands lie within the western and

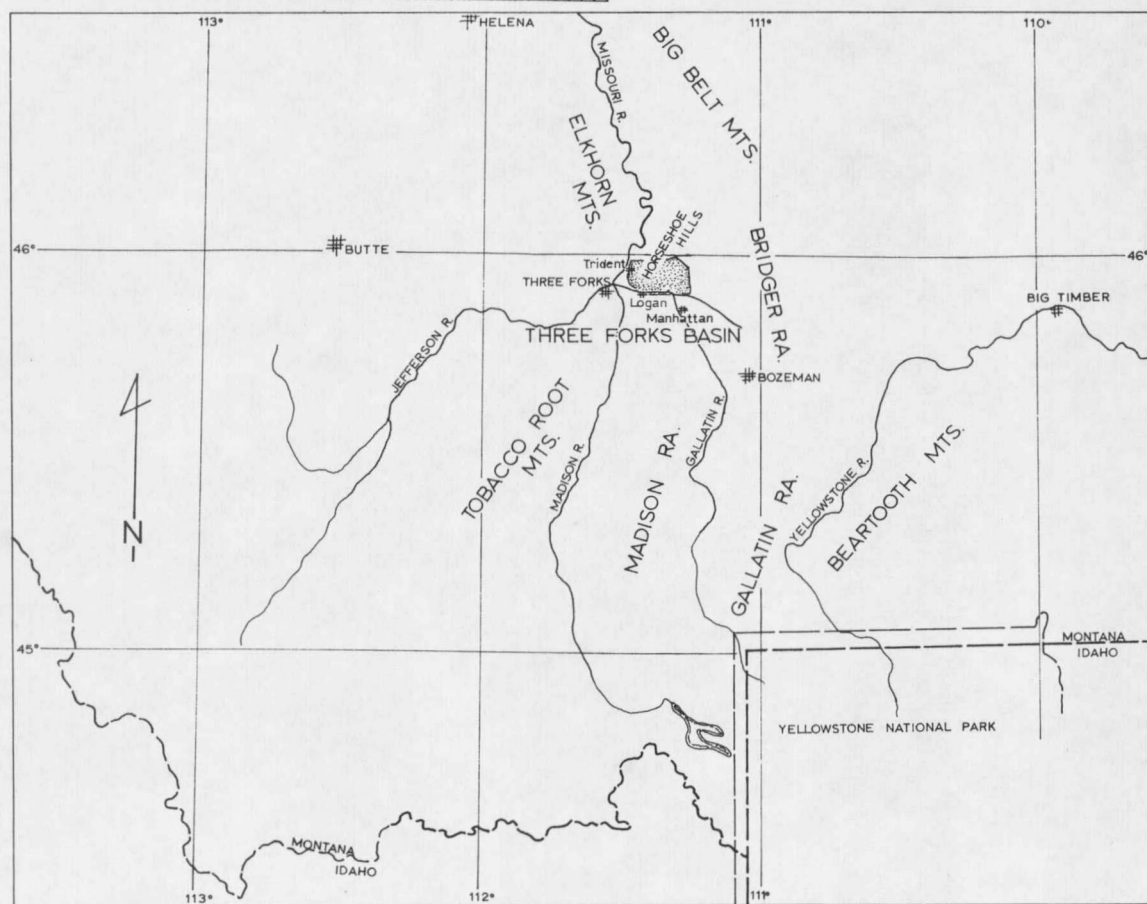
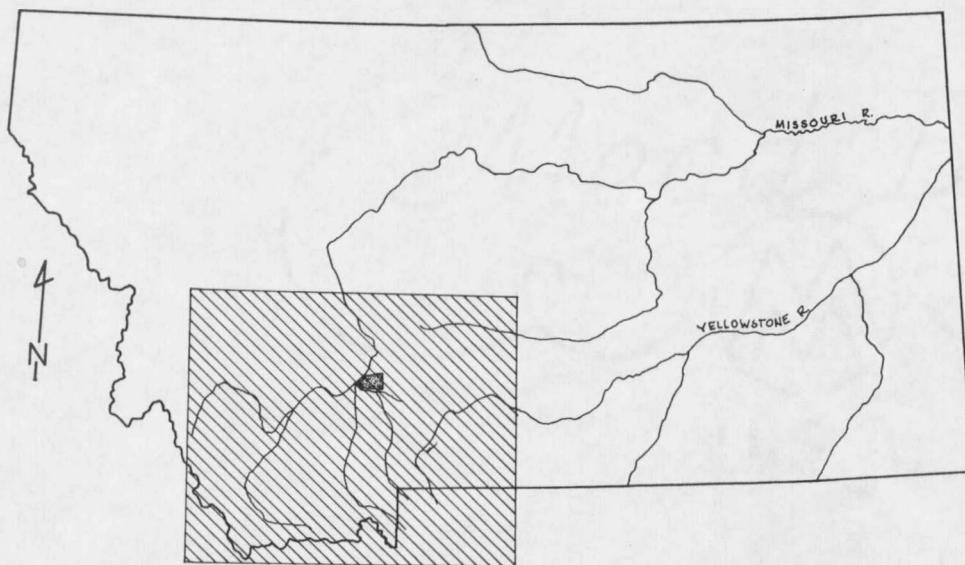


Figure 1 - Index Map

southern limits of the area studied. Maximum local relief is 1000 feet. Resistant rocks are generally moderately well-exposed, although in areas of low relief outcrops are rare. Good exposures of non-resistant formations are uncommon; these outcrops are produced only by the deepest stream incision and excavations of man. Topography corresponds closely to lithology, with trellis drainage patterns predominant. Figure 2 is an aerial view of the area showing the general nature of topography, vegetation, outcrops and structure.

Natural Setting

The north temperate semiarid climate is characterized by long windy cold winters, warm wet springs, hot dry summers, and long clear autumns. Maximum winter temperatures are generally near freezing with minimum temperatures often well below zero. During the summer, daytime temperatures are commonly in the 90's, but the nights are cool. The area receives 10 to 14 inches of precipitation per year, mostly as winter and early spring snow. Geologic field work is possible at times during any month of the year. From mid-December through February occasional warm spells may be utilized. During November to mid-December and March, field work is somewhat uncomfortable but feasible. The remainder of the year is quite pleasant.

Most of the Horseshoe Hills is rangeland. Trees are locally present along stream courses and at the uppermost elevations. Sagebrush grows on shales and igneous rocks. Carbonates, sandstones, sandy shales, and gravels support grasses and scrubby trees. Deer, antelope, rattlesnakes,



Figure 2 - Central Folded Section,
looking north.

and a variety of birds are the principle forms of wildlife. Rattlesnakes, a notable menace in the past, are now greatly reduced in number as a result of the efforts of individual landowners.

Land Use

The land is devoted almost exclusively to agriculture. Most of the area is semi-open range for cattle and horses. Flat uplands near the western and southern peripheries maintain scattered dry farm wheat fields. Only two ranches within the mapped portion of the Horseshoe Hills are occupied at present, the remainder of the land being managed by farmers living in surrounding valleys. A number of abandoned homesteads attest to the wetter years and less mobile society of the past. The two small towns of Logan and Trident lie near the border of the area and the towns of Manhattan and Three Forks are within five miles distance. Several small quarries are supplying, or have supplied, limestone and sandstone for cement-making, shale for brick-making, and building stone. Numerous gravel pits supply road material.

Access

The road system is primitive but adequate. Most of the roads can be negotiated by conventional automobiles, although some difficulty may be encountered crossing hogback ridges and in the vicinity of springs and melting snowbanks. A four-wheel drive vehicle can reach virtually any outcrop in the area.

Previous Investigations

A classic geologic study of the region was done in the 1880's by Peale (1896), who mapped the Three Forks 1-degree quadrangle at a scale of 1:250,000 and published his results as a part of the geologic folio series. His work, which was of a reconnaissance nature, outlined the broad stratigraphic and structural features. Verrall (Unpub. Ph.D. dissertation, Princeton Univ., Princeton, N. J., 1955) studied the Horseshoe Hills, but never published his work. Numerous stratigraphic and paleontologic studies include data from the Horseshoe Hills and are cited under the appropriate headings in the text. Adjacent areas recently investigated include the Bridger Range to the east (McMannis, 1955), the Garnet Mountain quadrangle to the south in the Gallatin Range (McMannis and Chadwick, 1964), the Three Forks quadrangle immediately to the west (Robinson, 1963), the southern Elkhorn Mountains to the northwest (Klepper, et al, 1957), the Toston quadrangle to the north (Robinson, 1967), and the Maudlow quadrangle to the northeast (Skipp and Peterson, 1965).

Objectives

The objectives of this study were to construct a geologic map, to describe the lithologic and structural features and their relationships, and to interpret the geologic history.

STRATIGRAPHY

Precambrian

Precambrian rocks of the region are of two major groups: the older metamorphic basement, and the younger sedimentary Belt Supergroup. Rocks of the basement complex are not found in the map area, but they are found a short distance to the south.

The basement rocks were formed during a sequence of metamorphic events that extended from 2,700 million to 1,500 million years ago (McMannis, 1965, p. 1803). Late in Precambrian time a north-south-trending geosyncline developed along the western margin of the continent. An extensive east-west embayment developed across central western Montana, and received large volumes of Belt sediment from a positive area to the south (McMannis, 1963). Sedimentary features and structural relationships show that a major east-west fault bordered the southern margin of the embayment, passing a few miles to the south of the map area.

LaHood Formation

In the southern Horseshoe Hills the Belt Supergroup is represented by the LaHood Formation, which consists of carbonate, argillite, and siltite, interbedded with arkose. Exposure of the formation is confined to a single belt of outcrops along the southern margin of the map area, where it is expressed topographically as a series of subdued hogback ridges and valleys. McMannis reports up to 4700 feet of LaHood strata present in the area, but the total thickness is unknown because the lower contact is not exposed. The upper contact is a major unconformity overlain by the

Middle Cambrian Flathead Formation.

LaHood lithologies found in the Horseshoe Hills represent a combination of the type LaHood arkose and argillaceous carbonates more typical of the type Newland. Despite the predominance of fine-grained clastics and carbonates, McMannis (1963) feels that the presence of arkose firmly relates the Belt rocks of the southern Horseshoe Hills to other more pronouncedly arkosic LaHood localities.

The arkose present is finer-grained than that to the east and west. Quartz and feldspar pebbles contained range up to 2 inches, but average one-half inch in length. Graded beds ranging from 1 to 15 feet thick show scour contacts at the base. The argillaceous carbonate is thin-bedded to laminated, dense, dark-gray, dolomitic limestone which commonly weathers tan. McMannis (1963, p. 416-7) recognizes one marker interval which consists of finely laminated carbonate beds with abundant biostromal algal colonies and is also characterized by "molar tooth" structures.

As noted above, the base of the LaHood is covered by valley fill to the south. Hackett and others (1960, p. 52 and Plate 2) have shown evidence for a buried major east-west fault (the Central Park Fault), which is aligned with a major fault lineament to the west recognized by other workers. This fault is located 3 to 5 miles south of the southern margin of the Horseshoe Hills. Sedimentary and structural relationships in the Bridger Range described by McMannis (1963 and 1965, p. 1802-3) indicate that this fault was active during the Precambrian.

Cambrian

Cambrian rocks in the Horseshoe Hills comprise a marine sequence approximately 1500 feet thick. The bulk of these rocks are subdivided and mapped as five formations. A sixth Cambrian formation is included with the Maywood Formation (Devonian) as a map unit. The Cambrian section is approximately 45 per cent shale, 42 per cent carbonate, and 13 per cent sandstone. Rocks in the area represent Middle and Late Cambrian time, possibly excluding latest Late Cambrian. Peale (1893, p. 20-25) first subdivided and described the Cambrian in the region. His rock units are readily recognizable, but names and boundaries have been greatly modified by his successors. Comprehensive regional studies of the Cambrian have been made by Deiss (1936), Hanson (1952), and Lochman (1956, 1957).

Flathead Formation

The Flathead is a tripartite formation consisting of upper and lower red-tinted quartz sandstones separated by an olive-green shale. It is commonly expressed topographically as two low, tree-covered ridges, separated by a grassy saddle. Thickness in the study area is about 160 feet.

The Flathead overlies the Precambrian LaHood Formation unconformably. The basal unit consists of thin- to massive-bedded, white, pink, red, and maroon, locally crossbedded, medium- to coarse-grained sandstone. Grains are dominantly subrounded, and conglomeratic lenses are common. Degree of induration is highly variable, ranging locally from very crumbly, non-

resistant sandstone to moderately hard orthoquartzite. The rock almost invariably breaks around the grains. Coloring is the result of iron oxide grain coatings. The unit is commonly exposed as a long dip slope, so the outcrop area is relatively wide. The thickness is 30 to 40 feet.

The basal sandstone grades upward to a drab-green, micaceous shale with subordinate interbedded limestone and sandstone in the adjacent Three Forks quadrangle (Robinson, 1963, p. 16-17). No good exposure of the unit is present in the map area, but float and sparse outcrops indicate that similar lithology is present. The unit is about 50 feet thick and forms a flat, sandy soil covered saddle.

The middle unit grades upward to a sandstone like that of the basal Flathead unit. Color ranges from white to red, and near the top, to maroon and dark red-brown. The unit is glauconitic, thin- to thick-bedded with crossbedding in places, medium-grained to finely conglomeratic, and ranges from friable to quartzitic. Thickness is highly variable, ranging up to 100 feet, but in places the unit seems to be very thin or absent. In places this unit forms a ridge which considerably overshadows the basal sandstone. Contacts of the unit are poorly exposed, leaving some doubt as to whether the prominent ridge-forming areas are the result of greater induration, unusually greater thickness, or both.

The Flathead is a basal transgressive marine sandstone, being oldest to the west. It is notably unfossiliferous, and has accordingly been dated as slightly older than the reliably dated, conformable, overlying Wolsey Shale. This reasonable assumption suggests that the Flathead was

deposited during the early Middle Cambrian, the Albertella time zone (Lochman, 1957, p. 132), and this has been recently substantiated by work of A. R. Palmer (U.S. Geological Survey, written communication to W. J. McMannis, 1965). Tysdall (Unpublished M.S. Thesis, Montana State Univ., Bozeman, 1966, p. 11-12) reports trilobites of the genus Glossopleura in the Flathead of the northern Gallatin Range, 35 miles to the southeast. According to A. R. Palmer (written communication to W. J. McMannis, 1965), the Glossopleura fauna occurs in the lower part of the Wolsey in the area just west of Three Forks. Whether this genus occurs in the upper Flathead as well in the thesis locality has not been determined. If it does, the Flathead is slightly younger here than was previously thought.

Wolsey Shale

The Wolsey is a drab green, micaceous shale with subordinate interbedded limestone and sandstone. It is transitional between the underlying Flathead Formation and the overlying Meagher Limestone. The Wolsey is represented topographically as a swale between the ridges of the adjacent formations. It has a thickness of about 350 feet in the thesis area. A recent study by Lebauer (1964) treats the formation regionally.

The lower contact of the Wolsey is chosen at the top of the uppermost thick Flathead sandstone bed. The Wolsey is an olive-buff, fissile shale and shaly mudstone, with interbedded thin sandstone layers lithologically similar to those of the Flathead. Worm trails and casts are

common in the sandstone. The interval grades upward to a green, fissile, micaceous, silty shale, locally interbedded with variegated green and red shaly limestone. Lebauer (1964) attributes the green coloring to the presence of illite, and to a lesser extent, chlorite. Rounded glauconite pellets of silt and sand size are widespread in the coarser phases of the formation. The uppermost unit is a buff to brown, fissile shale with interbedded thin silty tan limestones which grade upward into the Meagher Limestone. For convenience in mapping, the upper transitional contact is placed at the base of the first massive Meagher ledge.

The upper part of the formation contains abundant Bathyriscus trilobites. Well-known collecting localities are located in Nixon Gulch below the high Meagher cliff in the central part of Sec. 23, T. 2 N., R. 3 E.

The Wolsey is early Middle Cambrian in age (Hanson, 1960, p. 208). The formation represents shallow water stable shelf deposits which accumulated during a part of the eastward transgression of the Cambrian seas.

Meagher Limestone

The Meagher Limestone is the lowest of the great cliff-forming Paleozoic carbonate formations. The predominant lithology is thin-bedded dark gray limestone with orange shaly partings which become highly convoluted in places. It is generally expressed topographically as a rounded ridge. The average thickness in the map area is 350 feet.

The lower contact of the Meagher is placed at the base of the first prominent limestone ledge above the Wolsey Shale. Three units are generally recognized in the formation (Lebauer, 1965, p. 429-430). Immediately above the Wolsey is an interval of thin-, irregularly-bedded, buff-gray, fine-grained, fossiliferous limestone. A minor amount of buff-gray, irregular shale laminae, locally mottled, is also present. The middle unit is dark-gray, fine-grained, dense, thin-bedded limestone. The bedding planes are inconspicuous except on weathered surfaces, where they are etched out, producing a rough texture on the surface of the otherwise massive outcrops. The upper unit is somewhat similar to the lower interval. It is buff- to dark-gray, thin-bedded, fine-grained, fossiliferous limestone, and locally exhibits "blue and gold" mottling. The upper contact of the formation is the base of the first thick shale of the overlying Park Shale. The formation weathers to a light gray color. White calcite stringers are common in the limestone.

The "blue and gold" limestone has been the source of much curiosity. In essence it consists of dark gray limestone with a slight bluish cast, interspersed with patches of orange mottling that has a silty appearance. Apart from the mottled pattern, the two types are similar to the gray limestone and shaly partings found throughout the formation. An analysis made by Hartzell (Ruppel, 1950, p. 18) showed the light-colored portion of the rock to be largely dolomitic, and the dark colored areas calcitic. The light-colored patches have a considerably higher insoluble content as well. Lebauer (1965, p. 430) attributes the orange coloring to the

presence of limonite. He (Lebauer, 1965, p. 428) recognizes three controls on mottling: depositional, organic, and diagenetic. Depositional mottling is primary, but organic and diagenetic mottling result from dolomitization, recrystallization, and iron-staining.

The Meagher Limestone is middle Middle Cambrian in age. Lochman-Balk (1956, p. 617) reports that it contains the Bathyuriscus-Elrathina zone. The formation was deposited in the eastward transgressing Cambrian sea on a stable shelf dotted with marine banks and shoals (Lebauer, 1965, p. 439). The Meagher thickens considerably to the northwest and southwest and thins eastward (Lebauer, 1965, p. 430).

Park Shale

The Park Shale is a non-resistant formation containing greenish shale and minor amounts of interbedded sandstone and limestone. It is generally seen as a broad grassy valley or gently inclined grassy slope between the limestone ridges of the underlying Meagher and overlying Pilgrim. The thickness is about 370 feet in the study area.

The underlying contact with the Meagher is transitional, and is chosen as the top of the highest thick limestone ledge. The Park is predominantly fissile, micaceous shale, with colors of greenish-, brownish-, and purplish-gray. A few thin limestones and glauconitic sandstones are interbedded with the shale. The limestone interbeds are most prominent near the bottom of the formation and locally may protrude through the soil that commonly mantles the interval. Limestone flat-pebble conglomerate,

similar to that of the overlying Pilgrim, is present in the upper part of the formation. The Park is distinguished from the Wolsey by fine-grained mica flakes: mica in the Wolsey is coarse-grained. The upper contact is placed at the base of the first prominent Pilgrim Limestone ledge.

The Park is of late Middle Cambrian age and forms an as yet unnamed faunizone (Lochman-Balk, 1956, p. 597, 601). The formation represents a brief regressive episode in the eastward transgression of the Cambrian sea (Sloss, 1950, p. 432). Facies distribution shown by Lochman (1957, p. 131) indicates that the source was to the east. The formation thickens northeastward to the Little Rocky Mountains (Lochman-Balk, 1956, p. 617).

Pilgrim Limestone

The Pilgrim is the uppermost resistant Cambrian formation. It is distinctly tripartite in the thesis area, consisting of a thin massive lower limestone, a medial flat-pebble limestone and shale, and an upper medium-bedded limestone. Topographically, the formation presents a thin prominent lower ledge separated from an upper massive cliff by a steep, rubble-strewn slope. The thickness is about 400 feet.

The basal unit is a 20 foot thick massive gray limestone, weathering buff, and locally showing gray and tan mottling. The rock is locally oolitic. The unit is distinct on air photos, where it locally appears as a fine dark tree covered line. The second unit is a thin- to medium-

bedded limestone with a considerable amount of interbedded shale. Much of the limestone is a yellow-tan flat-pebble conglomerate. The interbedded shale is olive-green and weathers to an olive-yellow color. The middle unit grades upward to the third interval which is lithologically similar to the first. This uppermost unit consists of buff-gray, medium- to massive-bedded limestone with some thin beds near the bottom, and a considerable amount of light brown and tan mottling that is partially oolitic. The mottling is thought to be the product of partial dolomitization of a pre-existing oolitic limestone (McMannis, 1955, p. 1395). The upper contact is placed at the top of the resistant limestone.

Lochman-Balk (1956, p. 617) reports that the Pilgrim is Upper Cambrian (Dresbachian) in age, containing the Cedaria, Crepicephalus, and Aphelaspis zones. According to Lochman (1957, p. 136) the area was essentially an extensive, shallowly submerged shelf, with gross physical conditions unchanged from Park time, but with more marked shallowness and turbulence of water. The Pilgrim thickens and grades to dolomite within a few miles to the west.

Cambrian and Devonian

The Snowy Range and Maywood formations are an interval of non-resistant (fine-clastics and carbonates) between the massive, cliff-forming carbonates of the Pilgrim and Jefferson formations. Their combined thickness ranges between 108 and 291 feet in the study area. Although the formations represent two systems with a major erosional interval between,

they are mapped as a unit because of their limited thickness and poor exposure. The contacts are taken as the top of the massive underlying Pilgrim Limestone cliff and the bottom of the lowest thick dolomite ledge of the super-jacent Jefferson.

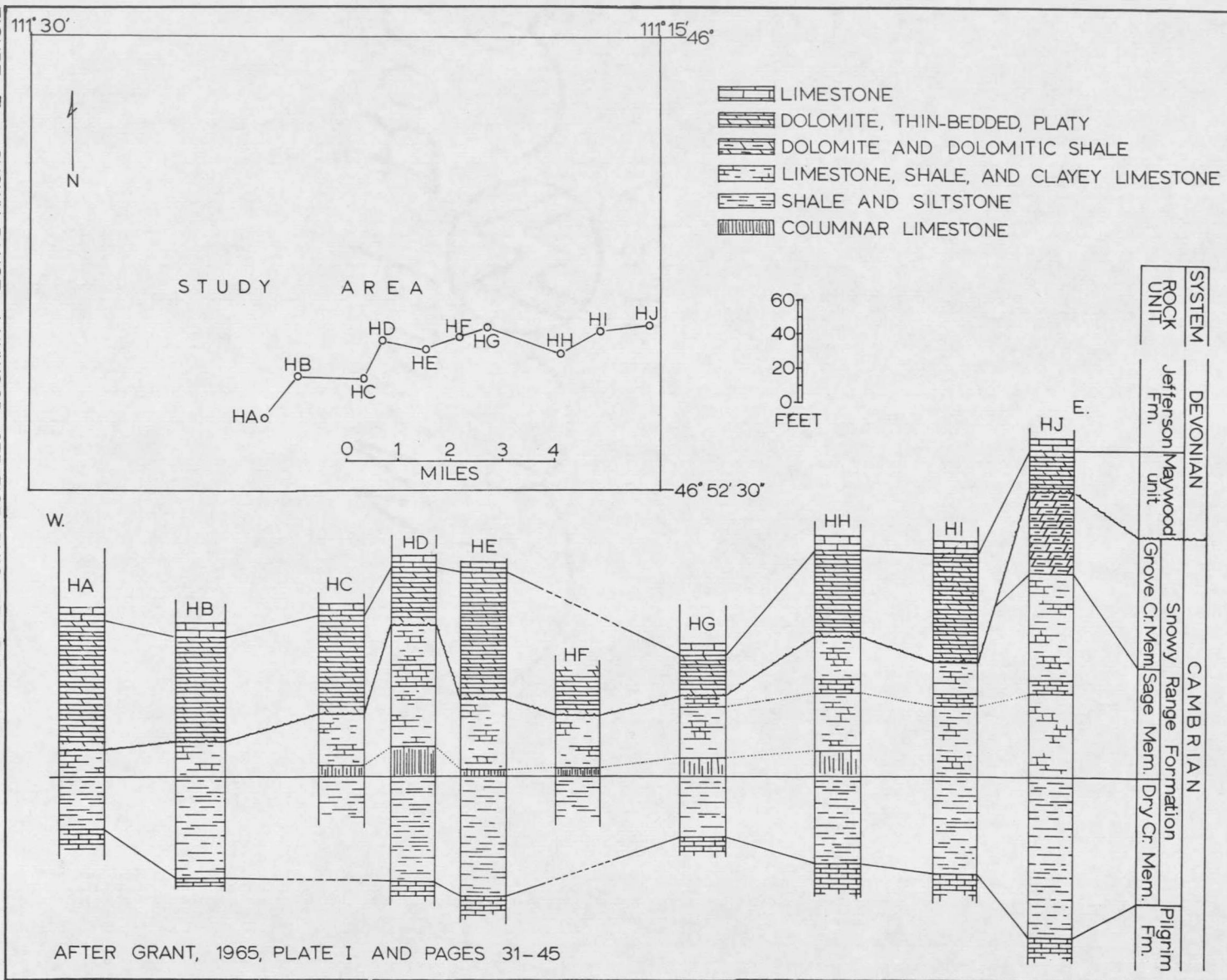
Lithologies, ages, and stratigraphic relationships are discussed under the appropriate individual formational headings. Grant (1965) has recently completed a comprehensive study of the Snowy Range interval, including detailed work in the Horseshoe Hills and adjacent parts of the region.

Snowy Range Formation

The Snowy Range Formation is the uppermost Cambrian deposit in the Horseshoe Hills. It makes up the lower part of the non-resistant interval between the Pilgrim Limestone and the Jefferson Dolomite. Thickness in the study area ranges from 50 to 265 feet. Stratigraphic relationships of the Snowy Range are shown in Figure 3. Grant (1965) recognizes three members: the Dry Creek (oldest), the Sage (Sage Pebble Conglomerate of Lochman, 1950, p. 220), and the Grove Creek (youngest). The top of the Snowy Range is marked by the Ordovician-Silurian unconformity, which exhibits 220 feet of stratigraphic relief and truncates beds of the Grove Creek and (in places) Sage Members. The following discussion summarizes his findings.

Dry Creek Member. The Dry Creek Member is a grayish-green, soft, fissile to crumbly, locally micaceous shale. The rock weathers purple and is poorly exposed, forming gentle slopes. As defined above, the lower

FIGURE 3 SNOWY RANGE — MAYWOOD STRATIGRAPHIC RELATIONSHIPS



contact is the top of the uppermost limestone ledge of the Pilgrim. The upper contact is the base of the columnar limestone or other distinctive Sage Member lithology. The thickness ranges from 30 to 55 feet in the map area.

Sage Member. The Sage Member is characterized by a variety of limestone types with intercalated grayish-green shale beds. It exhibits a basal columnar limestone formed by the calcareous algae Colleniamagna. Columns are commonly 8 to 18 inches in diameter and 1 to 6 feet high, with pebbly limestone filling the space between columns. Elsewhere in the region the lower part of the Sage Member may consist of 1 to 4 such layers, separated by thin layers of shale and limestone conglomerate (Grant, 1965, p. 12). The upper and major portion of the Sage Member is thin-bedded, fine- to medium-grained limestone and limestone pebble conglomerate intercalated with beds of shale or shaly limestone. Thickness of the member varies from 15 to 120 feet in the Horseshoe Hills, averaging 55 feet. Grant (1965, p. 13) estimates that the average pre-erosion thickness was approximately 200 feet.

Grove Creek Member. The uppermost member of the Snowy Range, the Grove Creek, is found at only one locality in the Horseshoe Hills, along the road in the SE $\frac{1}{4}$, sec. 17, T. 2 N., R. 4 E. Elsewhere it has been removed by pre-Devonian erosion. The member consists of a resistant yellowish-orange limestone or limestone conglomerate with hard, calcareous, gray shale. The upper part has been removed by pre-Devonian erosion at all known occurrences of the Grove Creek Member.

The Snowy Range Formation is Late Cambrian in age. The very lowest beds are latest Dresbachian, but most of the formation is Franconian. The formation represents deposits formed in the waning Cambrian sea. The Sage Member was deposited far offshore under shallow, turbid conditions. Greater abundance of fine clastics in the Dry Creek and Grove Creek members suggests that they were more closely associated with terrigenous influences. Although the contact with the Pilgrim is a sharp lithologic break, no evidence of subaerial erosion has been found. The superjacent gap between Cambrian and Devonian fauna and relief on the erosion surface that marks the top of the formation indicate a major erosional interval following Snowy Range deposition.

Cambrian-Devonian Unconformity

Ordovician and Silurian strata are absent in the Horseshoe Hills. The only surviving evidence of this long interval is the disconformity between the Snowy Range and Maywood formations which exhibits 218 feet of stratigraphic relief and a gap between Cambrian and Devonian faunas.

The Bighorn Dolomite (Late Ordovician) is not present in the study area but is found in nearby areas to the southeast (Roberts, 1964a, and Sloss and Moritz, 1951). The lack of clastics near the edge of the Bighorn plus the extensive time available for erosion is strongly suggestive that the Bighorn was deposited over a much wider area than that in which it is now found, and that it was subsequently removed by erosion. Therefore, the Bighorn may have been deposited in the Horseshoe Hills.

The Silurian Period apparently was a time of erosion in nearly all

of Montana. The nearest Silurian strata are in Idaho to the south, and in northeastern Montana in the subsurface of the Williston Basin.

Maywood Formation

The Maywood Formation is a non-resistant, red-orange, silty, dolomitic interval. It forms the upper part of the relatively non-resistant section between the massive cliffs of the underlying Cambrian Pilgrim Limestone and the overlying Devonian Jefferson Dolomite. Thickness in the thesis area ranges from 25 to 65 feet. Recent work by Grant (1965) comprehensively treats the Maywood in this area and the adjoining region. Stratigraphic relationships are shown in Figure 2.

The base of the Maywood is concordant with the underlying Snowy Range Formation. In some places a gradual lithologic transition exists from the unaltered Snowy Range upward to Maywood. Grant (1965, p. 19) places the base of the formation at the horizon above which no fossils or glauconite occur. The lower part of the Maywood is a reddish-orange, thin-bedded, silty dolomite and dolomitic limestone. The Maywood beds become increasingly brown and petroliferous upward, and except for their thin-bedded and non-resistant character, strongly resemble the superjacent Jefferson Dolomite. The upper contact is conformable and chosen at the base of the lowest prominent 3 foot resistant ledge of limestone or dolostone of the Jefferson.

The Maywood is commonly unfossiliferous. However, Sandberg and McMannis (1964) have described outcrops 30 miles south of the Horseshoe

Hills containing abundant Late Devonian Bothriolepis sp. fish remains. On the basis of fossils from the upper part of the formation at Milligan Canyon a few miles west of the area, Klepper and others (1957, p. 13) assign an age of latest Middle or earliest Late Devonian. According to Sandberg (1961, p. 1307) to the east the lower part of strata commonly included in the formation may be as old as Early Devonian (?) and equivalent to the Beartooth Butte Formation. Throughout the region Maywood lithology is found immediately below the Devonian Jefferson Dolomite, although it overlies various Cambrian and Ordovician formations.

The Maywood environment of deposition has been the subject of some controversy. Grant (1965, p. 18) concluded it represents a weathering zone developed prior to the advance of the Jefferson sea. He based his conclusion on erratic thickness, variable depth of "weathering penetration," and variety of underlying formations. As a paleosoil, the Maywood is unworthy of formational status according to Grant. In earlier work, Lochman (1950, p. 2221) reached somewhat similar conclusions, although she admitted the close proximity of the coast of the Jefferson sea and the possibility of marine reworking of the weathered zone. These explanations are not entirely adequate to explain such features as conspicuous good bedding, carbonate strata, salt casts, marine fossils, channel filling, and the like. Sandberg and McMannis (1964) and McMannis (personal communication, 1967) admit the existence of some pockets of unworked regolith, but feel that the preponderance of the rocks of the formation were deposited in marine or transitional environments. They show evidence

for an east-west trending paleoshoreline a few tens of miles south of the Horseshoe Hills.

Devonian

The Devonian System in the Horseshoe Hills represents a continuation of marine sedimentation following a long erosional interval that lasted from latest Cambrian through Middle Devonian. Rocks of the system are subdivided into four formations, the Maywood (previously discussed), Jefferson, Three Forks, and Sappington, which are included in all or part of three map units: the Snowy Range-Maywood, Jefferson, and Three Forks-Sappington. The Sappington is transitional upward into the lowest Mississippian.

Sloss and Laird (1947) and Benson (1966) have published regional Devonian stratigraphic studies, and Andrichuk (1951) analyzed the region-wide sedimentary environment.

Jefferson Dolomite

The Jefferson is a thick sequence of mainly carbonate rocks which forms a massive ridge between the valleys of the non-resistant underlying Snowy Range - Maywood and overlying Three Forks. The characteristic rock type is coarsely crystalline to saccharoidal, fetid, dark brown dolomite or dolomitic limestone. The thickness is 470 feet near Logan at the southwestern margin of the map area.

The lower Jefferson contact is conformable and is placed at the base of the lowest massive resistant carbonate ledge. Lithologically the

Jefferson consists of distinctive medium-bedded to massive, gray to brown dolomite, dolomitic limestone, and limestone with subordinate interbedded greenish argillaceous carbonates, and zones of solution breccia. Minor amounts of nodular and fragmental black and gray chert are present throughout much of the formation. The formation tends to be more dolomitic in the lower part. Commonly the beds have a strong petroliferous odor, resulting from hydrocarbon film on individual grains and tiny interstitial hydrocarbon pellets (Robinson, 1963, p. 27). Solution breccias, dolomite pebble conglomerates, and "spaghetti beds" are characteristic, although their volumetric proportions from section to section are highly variable. The "spaghetti beds" are masses of slender closely packed, "twig-like" tubes about 0.1 inch in diameter with lengths ranging up to 1.0 inch, and have been variously interpreted. According to Helen Duncan (quoted in Robinson, 1963, p. 26) they were probably formed by the dendroid stromatoporeid Amphipora. Also present, although in less abundance, are silicified "cabbage head" stromatoporeids.

The upper contact with the Three Forks Formation is conformable, but sharp. It is placed at the base of the lowest sequence of thin-bedded orange siltstone and limestone. In many places this is very close to the stream course at the base of the Jefferson dip slope.

Several earlier workers (Sloss and Laird, 1947; Andrichuk, 1951; Wilson, 1955) attempted to subdivide the Jefferson, but most classifications proved to be at best locally usable and failed to gain general acceptance. The only workable subdivision is the separation of the upper

50 to 90 feet (70 feet near Logan) of the formation. This upper unit consists of medium- to coarse-grained, light-colored dolomite. The unit has been correlated with the Birdbear Formation of the subsurface Williston Basin by Sandberg and Hammond (1958) and has been named the Birdbear Member by Sandberg (1965, p. N6). It is separated from the lower part of the formation by a persistent solution breccia and/or shaly dolomite zone of variable thickness. Sandberg (1965, p. N4) has named the lower interval the Lower Member. A conspicuous light colored mottled interval is well displayed in the lower part of the Nixon Gulch section, and according to McMannis (personal communication, 1967) seams to be present in the Bridger Range and northern Gallatin Range.

The Jefferson thins to the southeast and becomes increasingly clastic. Solution breccia decreases to the southeast (McMannis, 1962, p. 8). The formation is the equivalent of the Darby Formation of Yellowstone Park and Wyoming.

The Jefferson is a shallow water marine deposit laid down in an environment well removed from terrigenous influence. Crossbedded saccharoidal beds suggest reworking of pre-existing dolomite or secondarily dolomitized crossbedded limestone. Cooper and others (1942, p. 1768-9 and Chart 4) and Laird (1947) have shown paleontologically that the formation is Late Devonian.

Three Forks Formation

The Three Forks is a varied assemblage of clastic and carbonate

rocks. The formation forms most of the valley between the massive ridges of the Jefferson Dolomite and the Lodgepole Limestone. The formation is generally poorly exposed, but where exposed is easily recognized by its abundant fossils and unique sequence of lithologies. The thickness near Logan is 184 feet. Two members are distinguished, a lower Logan Gulch Member and the overlying Trident Member, according to the recommendation of Sandberg (1965, p. N10), but Sandberg's Sappington Member, overlying the Trident is herein recognized as a separate formation. The nomenclatural usages of this paper and other recent studies are compared graphically in Figure 4.

The Logan Gulch Member is an evaporitic, nonfossiliferous, brecciated, argillaceous carbonate interval. It contains in large part discontinuous beds of yellowish- and reddish-gray argillaceous limestone and shale, although the basal beds are dolomitic, and the upper part is a brown-gray massive limestone. The thickness near Logan is 111 feet. The member is generally non-resistant, but the upper limestone locally forms a weak ridge in the center of the valley between the massive Jefferson and Lodgepole ridges.

Deposition was in a large evaporite basin centered in northwest Montana, and the study area was part of an offshore evaporitic facies, according to Sandberg (1965, p. N10-11). The Logan Gulch extends laterally in all directions to the limits of the Three Forks Formation, and despite some lithologic variations, retains its evaporitic character throughout.

<u>Sandberg, 1965</u>			<u>McMannis, 1962</u>			<u>Rau, 1962</u>			<u>Sandberg, 1962</u>			<u>This paper</u>		
D E V O N I A N	MISS.	Lodgepole Limestone	MISS.	Lodgepole Limestone	MISS.	Lodgepole Limestone	MISS.	Lodgepole Limestone	MISSISSIPPIAN	Lodgepole Limestone				
		Dark Shale unit		basal black shale				black shale mem						
		Three Forks Formation		Sappington Member		Sappington Formation		Three Forks Formation		Sappington Ss. Mem.	Sappington Sandstone Member	Sappington Formation		
				Trident Member						Horse-shoe Hills Member			shale member	Trident Member
			Logan Gulch Member		London Hills Member		evaporite member		Logan Gulch Member					
		Jefferson Dolomite		Jefferson Dolo.		Jefferson Dolomite		Jefferson Dolomite						

The Trident Member extends upward from the top of the uppermost brown-gray massive limestone of the Logan Gulch Member to the base of the thin tan-gray to black carbonaceous shale of the basal Sappington. It consists largely of greenish and yellowish fossiliferous calcareous shale, capped by a massive limestone or shale zone containing limestone nodules. The basal portion is yellowish dolomitic limestone and silty dolomite. The thickness at Logan is 73 feet. The upper contact is marked by a disconformity which is indicated by significantly different fossil assemblages above and below as well as local evidence of erosion at the contact (McMannis, 1962, p. 10). Up to eight inches of local relief are present in the exposure of the disconformity just west of Nixon Gulch.

According to Sandberg (1965, p. N13) the member was deposited in a shallow, muddy, open or locally restricted, marine shelf area. The shale thickens and the capping limestone disappears to the west.

The Trident Member of the Three Forks contains numerous fossils of the Late Devonian Cyrtospirifer zone (Gutschick, 1964, p. 173), and since the underlying Jefferson Formation is also of Late Devonian age, the age of the Logan Gulch Member is also firmly established as Late Devonian.

Sappington Formation

The Sappington Formation is a thin interval of non-resistant yellow- and olive-tinted silty clastic beds. It forms the stratigraphically higher part of the valley between the prominent ridges of the Jefferson and Lodgepole formations. The thickness near Logan in the area studied is

57 feet. Because of its limited thickness, the Sappington is mapped with the Three Forks Formation.

Five distinct lithologic units of the Sappington are generally recognized (Sandberg, 1962 and 1965; Achauer, 1959; and Gutschick, Suttner, and Switek, 1962). These are, from the base upward: (1) thin tan-gray to black carbonaceous shale; (2) thin, resistant, olive-tinted, fossiliferous, fetid, silty argillaceous limestone and argillaceous calcareous siltstone; (3) resistant, interbedded, yellow and olive siltstone, silty shale and shale; (4) light-colored, olive- and green-gray calcareous shale with thin interbeds of yellow siltstone; and (5) resistant yellow calcareous siltstone and fine-grained sandstone. The lower contact with the underlying Three Forks Formation is a regional unconformity and is exposed at a few places in the study area. The upper contact with the black shale member of the Lodgepole Limestone is unconformable, as is demonstrated by the member's progressive truncation of older rocks southwestward (Sandberg, 1963, p. C19).

Considerable controversy concerning the name, age, and limits of this interval has existed since it was first named by Berry (1943). Robinson (1963, p. 34-38) gives a thorough review of the developments in the "Sappington Problem." Formational status of the unit is herein accepted, following the recommendation of Gutschick, Suttner, and Switek (1962) and McMannis (1962, p. 10). Although the Sappington is generally unmappable, formational status is merited by its distinctive lithology and wide areal extent. Such usage is consistent with terminology applied

to other thin but distinctive formations in the area, in particular the Maywood Formation and formations of the Ellis Group.

The thin, persistent black shale underlying the limestone of the Lodgepole has been included with the Sappington by some authors. In this study it is included as a basal unit of the Lodgepole, following the suggestion of several recent workers, including McMannis (1962, p. 10) and Sandberg (1965, p. N16). The regional unconformity between the black shale and the underlying Sappington clearly separates them.

A biostratigraphic study by Gutschick (1964, p. 172) has shown that the Devonian-Mississippian systemic boundary lies within the Sappington Formation. Precise location of the boundary is uncertain, but the lowest Sappington beds are Famennian (latest Devonian) and the upper beds of the formation are Kinderhookian (earliest Mississippian).

The Sappington Formation was deposited in an extremely shallow regressive sea in a marginal-marine environment (Sandberg, 1965, p. N16). Gutschick, Suttner, and Switek (1962, p. 87-88) describe an initial environment of small shallow lagoonal basins of restricted, quiet circulation and reducing conditions. This was succeeded by an interval of shallow marine conditions on a wide shelf with open circulation, which was in turn followed by an environment of marginal marine and brackish mud and silt tidal flats. Eventually this environment was encroached upon by alluvial fine-clastic sediments. McMannis (1962, p. 10-11) suggests that a possible source of the clastic material was reworking and concentration of material contained in older Devonian beds, such as the Darby to the Southeast.

The formation is persistent and lithologically consistent over a wide area of western Montana (see McMannis, 1965, Fig. 5 and Gutschick, Suttner, and Switek, 1962, Fig. 2 and 3). Sandberg (1965, p. N16) states that the Sappington is the southern equivalent of the Exshaw Shale in the subsurface of northwestern Montana and southern Alberta.

Permo-Carboniferous

The Mississippian, Pennsylvanian, and Permian systems are represented by six formations in the Horseshoe Hills, and are mapped in five units. Mississippian rocks include the upper part of the Sappington Formation, the Lodgepole Limestone and the Mission Canyon Limestone of the Madison Group, and an uncertain amount of the Amsden Formation. The Mississippian Big Snowy Group is absent in the study area, but is present within a few miles to the northwest, and within 15 miles to the east (McMannis, 1965, Fig. 6). The Pennsylvanian System may encompass all or part of the Amsden Formation and probably includes the Quadrant Formation. The Phosphoria Formation is Permian.

Thickness of the interval ranges from about 2100 to 2400 feet in the thesis area. The thin Sappington Formation is mapped with the underlying Three Forks, and the Phosphoria and Quadrant are mapped as a single unit because of the thinness of the Phosphoria. The Lodgepole, Mission Canyon, and Amsden are mapped individually. The Madison limestones are comparatively thick and comprise the greater part of the Permo-Carboniferous interval.

Lodgepole Limestone

The Madison Group, which includes the Lodgepole and Mission Canyon limestones, is the uppermost of the Paleozoic cliff-forming carbonates. In the Horseshoe Hills, Lodgepole outcrops are marked by steep, rugged slopes broken by scattered outcrops and ledges. The dominant lithology is dark gray, thin- to medium-bedded micro-crystalline limestone that weathers to a light yellow-buff color. The thickness is about 700 feet throughout the area studied.

The base of the Lodgepole is marked by an unconformity at its contact with the underlying Sappington Formation. The basal black shale member is a gray to black carbonaceous dolomitic silty shale. This unit has been correlated with the Little Chief Canyon Member of the Lodgepole by some past workers, for example Knechtel and others (1954), although the two are geographically separated. Sandberg (1963, p. C18) shows that the southern limit of the Little Chief Canyon Member lies near the Little Rocky Mountains, 160 miles northeast of the study area. The thesis area is within a few miles of the westernmost extent of the black shale member, but the beds extend for several hundred miles to the east and south (Benson, 1966, Fig. 16). The member is overlain by the thick limestone sequence that makes up the bulk of the Lodgepole. Sandberg (1963, p. C19) reports that the lower contact with the Sappington is disconformable, showing that southeastward the basal black shale member truncates progressively older rocks, ranging from earliest Mississippian to early Late Devonian.

Dark-gray microcrystalline limestone that weathers yellow- to olive-buff is common throughout the Lodgepole sequence. The formation becomes coarser upsection, and is sucrose in places. Calcareous mudstone partings of a yellowish color are common in the lower several hundred feet, but decrease upsection. The coarse-grained intervals commonly have a fetid odor. Fossils are common, and are in such abundance that they are usually found in even the smallest outcrops. Typical forms present are brachiopods, corals, bryozoans, and crinoids. Small amounts of nodular chert are locally present in the upper and lower parts of the formation. The upper Lodgepole contact is placed at the base of the lowest massive-bedded limestone ledge typical of the overlying Mission Canyon Limestone. The Lodgepole is of Early Mississippian age, ranging from middle Kinderhookian to early Osagian (Sando and Dutro, 1960). The formation formed in a shallow marine environment characterized by mild wave action and slowly fluctuating depth. Stability and water depth increased slowly but steadily throughout Lodgepole time (Robinson, 1963, p. 40-41). The Lodgepole is one of the most widespread formations of the northern and middle Rocky Mountains as well as the plains region.

Mission Canyon Limestone

The Mission Canyon Limestone is the upper of the two formations comprising the Madison Group in the Horseshoe Hills. The formation is a consistently massive, light gray-brown, limestone, which forms rounded ridgetops and long dip slopes. Outcrop areas include large flat patches

of barren rock with no soil. These barren patches are conspicuous on aerial photographs. The thickness near Logan is about 1050 feet.

The lithologic differences between the Mission Canyon and the underlying Lodgepole are not too conspicuous, but there is a marked and abrupt change from the thin- and medium-bedding of the Lodgepole to the massive, indistinct bedding of the Mission Canyon. The reddish tints, locally saccaroidal texture, and profusion of fossils of the upper Lodgepole give way to pale drab colors, crystalline and oolitic texture, and less conspicuous fossils of the Mission Canyon. The conformable contact is placed at the base of the lowest massive limestone bed. Beds in the Mission Canyon range from 3 to 10 feet in thickness, with a few thin-bedded sequences.

The predominant lithology is a light brown-gray micro-crystalline limestone that weathers to a light gray color, although a considerable portion is coarsely-crystalline and some oolitic beds are present. Mudstone layers and fossils are generally lacking. The formation is characterized by chert in the form of false-nodules, nodules and reticular masses. The chert ranges in color from yellow to olive to black, and becomes increasingly prominent upsection.

Limestone breccia zones are exposed in several areas. These solution or collapse breccias are apparently characteristic of the upper part of the formation, and are also reported in adjacent areas (McMannis, 1955, p. 1400-1401; Robinson, 1963, p. 42-43; Middleton, 1961; Andrichuk, 1955; and Roberts, 1966b). The breccia zones are in part stratigraphically

localized, and in some cases can be used as horizon markers. The recemented detritus contains unsorted angular limestone rubble identical to the undisturbed portions of the formation. The fragments range from granule to boulder in size and are contained in a matrix of orange to red or gray-brown calcareous siltstone that locally shows lamination.

The upper contact with the overlying Amsden is disconformable. The generally covered contact lies at the base of the long Mission Canyon dip slope and usually must be mapped at the beginning of red soil that is commonly, but not universally, developed on the Amsden. Rocks of the Big Snowy Group were not found in the study area, but their presence in scattered localities to the west, north, and east (Robinson, 1963, p. 43 and McMannis, 1965, Fig. 6), but not in the study area, is evidence of a pre-Amsden disconformity. McMannis (quoted in Tysdal, unpublished M.S. Thesis, Montana State University, Bozeman, 1966, p. 32) cites lack of evidence of shoreline features in the Big Snowy as further indication of post-Big Snowy, pre-Amsden erosion rather than stratigraphic pinchout of the beds.

The Mission Canyon is of late Early (late Osage) to early Late (early Meramec) Mississippian age (Sando and Dutro, 1960, p. 117-123). The formation formed under conditions slightly modified from those prevailing during Lodgepole time. The Mission Canyon was deposited under deeper conditions with greater stability and lower wave energy, (Robinson, 1963, p. 43). It is generally concluded (McMannis, 1955, p. 1401; Klepper and others, 1957, p. 20; and Robinson, 1963, p. 43-44) that the

solution breccia formed in near-surface caverns during a post-Madison, pre-Big Snowy erosional epoch, prior to the transgressive Big Snowy deposition, where the latter did occur. In the adjacent Three Forks quadrangle (Robinson, 1963, p. 43), thickness measurements and truncation of the uppermost Mission Canyon beds indicate deep pre-Amsden erosion in areas where the Big Snowy is missing.

Amsden Formation

The Amsden Formation is a variably resistant, heterogeneous assemblage of clastic and carbonate rocks. In the Horseshoe Hills, the formation is represented topographically as an area of subdued strike gullies and ridges along the base of the Mission Canyon dip slope. Scattered outcrops are present in most of the study area, but continuous sections are rare. The thickness ranges from 300 to 400 feet.

The lower disconformable contact with the Mission Canyon is not well exposed, but is placed at the upper limit of the resistant Mission Canyon limestone, which contrasts with the non-resistant basal Amsden. This stratigraphic horizon is generally coincident with stream courses in the Mission Canyon dip-slope valley, and is also marked by the limit of reddish soil that typically forms on the Amsden.

Clastics, are dominant in the lower part of the formation, becoming subdominant in the upper part. Clastic rocks include fine-grained sandstone, siltstone, mudstone, and some shale. Red coloring is characteristic, although other colors, especially yellows, are also found, particularly

in the mudstones. Hematite pigment is common throughout the formation, and in addition detrital chlorite is widespread in the sandstones and siltstones. The clastics become increasingly well-sorted sandstone layers identical to those of the Quadrant Formation.

Carbonates, which are dominant in the upper part of the formation, are light pink, tan, gray, and yellow, and are silty, cherty, finely crystalline and sucrose, commonly displaying pinpoint porosity. Carbonates become increasingly dolomitic upsection. A few sucrose beds near the middle of the formation contain silicified brachiopods and corals.

The upper contact is transitional, and is placed where sandstone becomes dominant. As such it is not a consistent horizon, but varies within a narrow stratigraphic interval in the map area.

Robinson (1963, p. 48-49) reports poorly preserved fossils indicating a Late Mississippian or an Early Pennsylvanian age of the beds in the middle part of the Amsden. McMannis (1955, p. 1402-1403) also cites fossil evidence from the Amsden suggestive of both Late Mississippian and Early Pennsylvanian age. It is apparent that the formation transcends the systemic boundary.

The Amsden is interpreted as a shallow water transgressive marine formation. Carbonate was probably derived from nearby exposures of Carboniferous limestone, but a clastic source would have had to have been more distant, possibly to the north or to the west in the vicinity of the Idaho-Montana border (Robinson, 1963, p. 49).

Quadrant Formation

The Quadrant Formation is a moderately-well to poorly exposed quartz sandstone and orthoquartzite that forms a subdued ridge. In areas of poor exposure, the formation produces a thin sandy soil, with many small scattered patches of rubble and low ledges, and supports a few widely scattered trees and bushes. Determination of thickness is difficult because of the generally poor exposure of both contacts, but it is apparent that thickness is variable and averages about 175 feet.

The Quadrant is a lithologically consistent, medium- to thick-bedded, medium-grained sandstone and orthoquartzite composed of subrounded grains. It is uniformly white or light-colored; where tinted it is usually light yellow, although pink is occasionally seen. The rock commonly weathers to gray-browns and yellow-browns. Fine- and coarse-grained beds are present in a very limited amount, and crossbedding is also locally present. Cementation is of two types: quartz overgrowth and calcite. The quartz overgrowth-cemented areas form notably more highly indurated rock. Distribution of the two types of cementation seems random, both stratigraphically and areally, as is suggested by the highly variable topographic resistance of the formation.

As noted above, the contact with the underlying Amsden is transitional, and the basal Quadrant contains thick carbonate layers which decrease in number and thickness upward. The upper contact with the Phosphoria is also concordant and is placed at the base of any distinctive Phosphoria lithology such as yellow siltstone, chert, or phosphatic

sandstone.

Thick bedding, local cross-stratification, and purity of the sand are all suggestive of shallow neritic or beach environment on a stable shelf. Shifting currents intermittently carrying terrigenous sediment elsewhere, could account for the interbeds of clastic limestone.

Fusulinids from near the top of the Quadrant in the southern Madison Range to the south of the Horseshoe Hills were studied by Henbest (1956, p. 60) and shown to be of Des Moines (late Middle Pennsylvanian) age. Cressman and Swanson (1964, p. 354) conclude on the basis of correlation from the Madison Range locality to Three Forks that the upper Quadrant contact approximates the Pennsylvanian - Permian systemic boundary.

Phosphoria Formation

The Phosphoria Formation is a heterogeneous assemblage of clastic and chemical rocks characterized by the presence of chert. The formation is generally exposed capping the ridge and dip slope of the Phosphoria-Quadrant hogback. The thickness of the Phosphoria in the map area ranges from 45 to 75 feet. The Permian rocks of the region have been extensively studied by Cressman and Swanson (1964) and others.

The lower contact with the underlying Quadrant Formation is placed at the base of chert-bearing rocks. Chert of the Phosphoria Formation is dull yellowish-brown or greenish-brown and very brittle, a property that contributes to the scarcity of outcrops. Sandstones in the formation are similar to those of the Quadrant-- quartzitic, yellowish, and locally

crossbedded-- but contain chert in greater abundance. Minor amounts of phosphatic skeletal material and glauconite are also found locally. The upper contact of the formation is marked by an important unconformity, but is generally poorly exposed.

The Phosphoria sequence is well exposed in the railroad cut near the Gallatin River in west-central sec. 26, T. 2 N., R. 2 E. The upper contact is not exposed, but is close to the top of the measured section. The formation includes:

Phosphoria Formation:	Thickness (feet)
Quartzite, orange-brown, very hard, clean, medium-bedded, cross-bedded in part, contains yellow, silty, dolomite flat pebbles, upper contact not exposed	13
Chert, yellow- and maroon-brown, in beds to 3 inches thick, interbedded with yellow, platy, dolomitic siltstone, bedding planes irregular, unit weathers to yellow-brown.	7
Quartzite, hard massive, maroon-brown, clean.	1
Chert, orange-brown, bedded, beds 1 to 12 inches thick, minor amounts of mudstone in irregular bedding planes.	5
Quartzite, very hard, cherty, brown, massive, contains some apatite (?) skeletal material.	5
Siltstone, dolomitic, yellow, platy, interbedded with dolomitic sandstone, pale yellow to white, coarse-grained, beds 1 to 8 inches thick, also minor amounts interbedded brown chert and chert breccia, unit weathers bright yellow, lower contact irregular.	17
Quadrant Formation:	
Quartzite, medium- to thick-bedded, pale yellow, clean, hard	

In recent work on the Permian rocks of the region, McKelvey and others (1956, p. 2826-63) subdivided and redefined the Phosphoria as the

Park City Formation, the Shedhorn Sandstone, and the Phosphoria Formation (a restricted usage). Cressman and Swanson's (1964) comprehensive study of the interval followed the new terminology, but most others have not. Because of complex intertonguing relationships, subtle lithologic distinctions, and limited thickness in this part of Montana, the detailed breakdown is impractical for this study, and the older definition of the Phosphoria is followed, i.e., that the Phosphoria includes all Paleozoic rocks above the Quadrant.

The Phosphoria is Permian in age. Cressman and Swanson (1964, p. 354) feel that the lower contact with the Quadrant closely approximates the Permian-Pennsylvanian systemic boundary. Permian deposition continued well into Middle Permian time in southwestern Montana, but exactly how much of Middle Permian time is represented is unknown (Cressman and Swanson, 1964, p. 354).

The Horseshoe Hills are near the areal limit of the formation. The Phosphoria thickens to the south and west. The eastern extent of the formation in the vicinity of the study area is not completely known, but is certainly within 20 or 30 miles. Cressman and Swanson (1964, p. 284) report 25 feet of Permian rocks 15 miles to the north in the Sixteenmile Creek area and 45 feet in Rocky Canyon east of Bozeman. Tysdal (Unpublished M.S. Thesis, Montana State University, Bozeman, 1966, p. 34-36) reports Phosphoria absent at the northern front of the Gallatin Range, 30 miles southeast of the area of this study; but a little farther south in the Garnet Mountain quadrangle McMannis and Chadwick (1964, p. 14)

report 105 to 119 feet of Phosphoria.

The extent of post-Phosphoria erosion is unknown, but apparently was not great in the map area. Several lines of evidence indicate near-shore conditions near the present limits of the formation, suggesting that erosion was limited. McMannis and Chadwick (1964, p. 14) note the increase of quartzite toward the areal limit of the formation. Cressman and Swanson (1964, p. 351-354) interpret the numerous burrows as evidence of shallow-water conditions. The chert breccia and conglomerates of Jurassic(?) age in the Bridger Range (McMannis, 1955, p. 1404), now known to be Phosphoria (personal communication, W. J. McMannis, 1967) are further evidence.

Cressman and Swanson (1964, p. 276) have described the Phosphoria environment of deposition in great detail. The Phosphoria was deposited in a shallow, regressive sea under conditions of relatively low salinity. Clastic source areas may have existed both to the northwest and northeast of the Horseshoe Hills. Chert accumulation was accentuated by the bypassing of clastic material locally, and inhibition of calcareous organisms by the low temperature and salinity.

Triassic

The general southwestward regression of the seas that began in the Permian continued into the Triassic. No Triassic deposits are present in the study area, the nearest occurrences being in the southern part of the Gallatin Range (McMannis and Chadwick, 1964) and Madison Range (Moritz, 1951), 30 to 40 miles to the south. Termination of Permian deposition

cannot be precisely fixed because of subsequent erosion, but apparently the erosion interval began during Middle or Late Permian and continued throughout the Triassic and Early Jurassic in the map area. It is possible the Triassic sediments were deposited in the map area and removed by subsequent erosion; if so, thicknesses were most likely not great.

Jurassic

Jurassic strata are present, although poorly exposed, throughout the study area. Included are the marine Ellis Group, consisting of the Sawtooth, Rierdon, and Swift Formations, and the non-marine Morrison Formation. The total Jurassic sequence comprises a 447-foot interval. The Jurassic rocks are mapped as two units, the Ellis Group and the Morrison Formation. A Jurassic section was measured at a locality of relatively good exposure about two miles north of Logan. The site is in the small gulch in the northwestern corner of sec. 19, T. 2 N, R 3 E.

Jurassic rocks reflect the increasingly extensive incursions of the fluctuating sea in which they were deposited. In the map area the Triassic erosion interval continued through the Early Jurassic. Deposition began in the Middle Jurassic and continued with brief interruptions into the Cretaceous.

Sawtooth Formation

The Sawtooth Formation is represented by a buff-gray blocky claystone that weathers yellow. The unit is 38 feet thick, non-resistant, and seldom exposed. The thin basal cherty conglomerate and the limestone

beds described in adjacent areas (Robinson, 1963, p. 55 and McMannis, 1955, p. 1405) are not present in the Logan section. The lower contact with the Phosphoria Formation is a major unconformity. The upper contact is conformable.

The formation thins abruptly northward, reflecting the depositional and erosional influence of the Belt Island high to the north of the Horse-shoe Hills. The Sawtooth is absent less than 15 miles to the north (Imlay, and others, 1948) and within the same distance to the northwest (Klepper, and others, 1957, p. 23). The formation was deposited in a normal marine environment (Peterson, 1957, p. 421) during the Bajocian and Bathonian stages of Middle Jurassic time (McKee, and other, 1956, p. 5).

Rierdon Formation

The Rierdon Formation is a 15-foot-thick ledge of medium-bedded oolitic and fossil-fragmental limestone. Its medium gray color weathers to light tan. The Rierdon Formation is conformable with the underlying Sawtooth Formation, but it is separated from the superjacent Swift Formation by a marked regional unconformity.

Regional distribution of the Rierdon Formation demonstrates the continued influence of the positive area to the north. This is supported by the presence of sand in the Rierdon in the northeastern part of the study area. The formation is absent in a section described by Imlay (1948) on North Fork of Sixteen Mile Creek, 15 miles to the north. However, the northern edge is erosional, produced during the short but relatively

widespread interval of erosion that followed Rierdon deposition. The Rierdon represents continued shallow marine sedimentation (Peterson, 1957, p. 425-426). It was deposited during the early and middle Callovian (late Middle Jurassic) (McKee, and others, 1956, p. 5).

Swift Formation

The Swift Formation is a ledge forming yellowish, calcareous, glauconitic, medium-bedded, quartzitic sandstone. Forty-six feet of strata are present in the Swift section near Logan. The lower contact is disconformable. The upper contact is a pronounced lithologic break, but is apparently conformable.

The Swift was deposited in the latest and most widespread of the Jurassic seas. Predominance of sand to the west in the formation is indicative of an important clastic source in western Montana (Peterson, 1957, p. 433). However, the conglomerate described by Klepper, and others, (1957, p. 23) a few miles to the west may be indicative of a more local source. The Rierdon - Swift erosional interval took place during the latter part of the Callovian. Swift deposition occurred during the early and middle Oxfordian (Late Jurassic) (McKee, and others, 1956, p. 5).

Morrison Formation

The Morrison Formation is an interval of brightly-colored clastic sediments. The formation is non-resistant, forming the major portion of the valley between the Quadrant-Phosphoria and Kootenai ridges. Morrison strata are 348 feet thick in the section near Logan. Red-brown, rubbly

soil is characteristic.

The Morrison rests conformably on the Swift Formation. The lower half of the formation is dominantly red mudstone. The upper half is primarily buff-white mudstone with flaggy yellow fine-grained sandstone and widely scattered thin yellow limestone beds. However, widely scattered red mudstone intervals are found in the upper half of the formation and yellow sandstones and limestones are also found in the lower half of the Morrison. The rocks are calcareous throughout. No coals or carbonaceous shales were observed. The upper contact with the Kootenai is unconformable. McMannis (1965, p. 1813) reports parts or all of the formation locally removed by pre-Kootenai erosion within 50 miles to the west. The contact is placed at the base of the first thick ledge of distinctive Kootenai "salt and pepper" sandstone.

The Morrison is dated as Late Jurassic in its type area in central Colorado (Simpson, 1926). Late Jurassic age has also been shown in the Sweetgrass Arch vicinity in central Montana (Brown, 1946, p. 246-247). Yen (1951 & 1952), working with fresh-water molluscan fauna near Harlowton, dated the Lower Morrison as Purbeckian (uppermost Jurassic) and the upper Kootenai as younger than earliest Cretaceous. Harris (1966, p. 166) cites a pollen study by Tschndy which supports the Cretaceous age of the Kootenai. In the absence of evidence to the contrary, workers in southwestern Montana have extended this dating to their area (for example, Imlay, and others, 1948, and Robinson, 1963, p. 57-58). Lithology of the formation is suggestive of a terrestrial fluvial environment of deposition.

Cretaceous

Cretaceous rocks are the youngest rocks in the study area showing appreciable deformation. Thickness in the Horseshoe Hills area is in excess of 2000 feet. Cretaceous rocks are mapped as two units, the Kootenai Formation and the Colorado Group.

Kootenai Formation

The Kootenai Formation is a tripartite non-marine sequence consisting of a basal resistant sandstone, a brightly colored non-resistant medial unit of various lithologies, and an upper thin fossiliferous limestone. Thickness in the map area is about 550 feet.

The basal unit of the Kootenai rests unconformably on the underlying Morrison Formation. This is the so called "Pryor Conglomerate" of Roberts, (1965, p. B55). It consists of a ridge forming light gray cross-bedded, thick- and massive-bedded sandstone and conglomeratic sandstone containing conglomerate lenses. The sandstone consists of well-sorted white quartz grains with scattered black chert grains, producing the "salt and pepper" effect. Rounded varicolored chert and quartzite pebbles make up the conglomeratic portions of the unit. These pebbles are found in conglomerate lenses associated with the cross-bedding of the sandstone, and widely but evenly disseminated through the conglomeratic portions of the sandstone.

The middle non-resistant unit is poorly exposed even in the most favorable locations. The rock is predominantly white, yellow, and red

mudstone, but varicolored sandstone, siltstone, and limestone is also present. Thin layers of white "salt and pepper" sandstone similar to that of the underlying basal unit are present in minor amounts.

The upper unit is a moderately resistant limestone averaging 15 feet in thickness. The gastropods are of no value as age indicators because replacement has destroyed the diagnostic internal structure, but they do serve to characterize a distinctive marker bed. The gastropod limestone is conspicuously absent in the Bridger Range (McMannis, 1955, p. 1406) but is reported by most other workers in the region west of there. The upper contact of the Kootenai is located at or within a few feet of the top of this unit.

The rocks of the Kootenai are similar to those of the Morrison, and represent a continuation of the fluvial non-marine environment of deposition. The coarse clastic basal unit reflects orogenic activity to the west (McMannis, 1965, p. 1813). Yen (1951, p. 1-3) has shown that the Kootenai in other parts of the state is of Early Cretaceous age. In the absence of definitive evidence to the contrary, this age is extended to the Horseshoe Hills area.

Colorado Group

The Colorado Group is a sequence of largely non-resistant, poorly exposed, clastic sedimentary rocks. The thickness of the Colorado is in excess of 2300 feet in the southern Horseshoe Hills. The interval has been tentatively correlated with the Mowry, Thermopolis, and Frontier Formations

and the lower shale and Eldridge Creek Members of the Cody Shale (Roberts, 1964b), but due to the lack of exposure the units were not mapped individually in this study. A measured section of the Colorado Group is included in the Appendix.

The lower contact is placed at the top of the Kootenai "gastropod limestone." The lower unit (Mowry (?) and Thermopolis(?) equivalents) is a non-resistant interval of dark shaly mudstones with thin interbedded red and yellow sandstones which become increasingly rich in volcanic clastics upsection. The basal portion is the host for a stratigraphically consistent sill zone found throughout the map area. The second unit (Frontier(?) equivalent) is predominantly light gray to yellowish-brown, fine-to coarse-grained, thin-bedded sandstone with yellow and gray interbedded shale. Volcanic-rich sandstones are also present. Near the middle of this interval are black shales with a few thin coal seams. The lower part of the upper unit (Cody Shale(?) equivalent) is non-resistant and poorly exposed, but upsection thin, cross-bedded, gray, glauconitic quartz sandstones become increasingly predominant. These are thought to correspond, respectively, to the lower shale(?) and Eldridge Creek sandstone(?) members of the Cody.

The Colorado Group includes late Early Cretaceous (Aptian and Albian) and part of the Late Cretaceous (Roberts, 1965, p. B-57). Deposition took place in the southern arm of the arctic sea that covered most of Montana during that time. The sedimentary record in the area reflects several east-west oscillations along the western edge of that sea (Roberts, 1965, p. B-54).

Post-Laramide Deposits

Eight post-Laramide deposits are recognized. Included are two distinctly different gravels and white tuffaceous beds of probable Tertiary age; and travertine, loess and older and recent alluvium. They have the unifying characteristics of poor consolidation, relatively little deformation, and poor exposure.

Because of the poor exposure and discontinuity of the material, much of it is unmappable. The loess is not mapped, and in general, only widespread areas of the other units are mapped. Conditions also preclude precise dating and correlation with established units. These objectives might possibly be reached in a study of a much wider area, but are beyond the scope of this thesis.

High-level Gravel

An interesting deposit of gravel is present within a few feet of the base of the aviation beacon atop the high limestone ridge almost exactly at the western boundary of sec. 35, T. 3 N., R. 3 E. This site, north of the mapped area, is the only known occurrence. The site is higher than all points within the area studied, although higher elevations exist along the same ridge within two miles to the northeast.

The sub- to well-rounded gravels are interspersed with limestone rubble over an area of a few hundred square feet. Pebbles range from 0.5 to 2.0 inches in diameter. Lithologies present include basalt porphyry, granite, yellow quartzite, micaceous quartz sandstone, clean gray

quartz sandstone, and a conspicuously flow-banded, almost glassy dacitic or andesitic porphyry.

Similar lithologic assemblages in other gravels of the surrounding area have not been reported. An immediately attractive explanation is that the gravel was transported for use as aggregate in the construction of the beacon. However, the limestone rubble present at the site is more suitable for aggregate, and is present in adequate amounts. Had the gravel been brought in for construction, it would have had to have been trucked many miles from some distant source and finally transported over a steep, rough trail.

The alternative explanation is that the gravel is the natural stream deposit of an unknown early Tertiary drainage system. Such an interpretation indicates Tertiary burial of essentially all of the Horseshoe Hills area. Conclusive proof awaits additional study of the region.

Tuffaceous Beds

This unit is widely present over most of the map area south of the Gallatin River, but is not present north of the river. It is best exposed in the bluffs on the east side of the Madison River floodplain, but numerous small exposures are present in road and stream cuts throughout the above-mentioned area.

The deposit has been described by Hackett (1960, p. 32-39), who recognized and mapped two units. However, within the area of this study

exposures are neither good enough, nor extensive enough, to warrant such subdivision, and the deposits are mapped as a single unit. Extensive exposures of the unit lie south of the mapped area.

The lower part of the deposit, unit 1 of Hackett (1960, p. 35-37), is well-stratified tuffaceous marl, siltstone, and sandstone, with some limestone and volcanic ash beds. The beds are white to light gray or cream-colored and stand as rounded cliffs. Hackett (1960, p. 35) cites the presence of ripple marks, limestone, even stratification, and ostracodes as evidence of lacustrine origin, but admits that some of the beds may have been deposited in other terrestrial environments. Eighty-three feet of these strata are exposed in the bluffs directly west of the Logan Cemetery in the northeast corner of sec. 33, T. 2 N., R. 2 E.

The upper part of the beds, unit 2 of Hackett (1960, p. 38-39), consists of massive, poorly stratified, buff to tan, calcareous, tuffaceous siltstone, claystone, sandstone, and gravel. It is gradational with the lower part in the area studied, but according to Hackett (1960, Fig. 7) is locally unconformable to the south. Bedding is discontinuous and crossbedding is conspicuous, suggesting predominantly fluvial origin, although marl and limestone beds indicate the presence of small lakes or ponds. Clastics become coarser upward, with the uppermost beds consisting almost entirely of gravel.

A hard quartz sandstone from the upper part of the sequence is exposed along the top of the hogback ridge south of the interstate highway in the SW $\frac{1}{4}$ sec. 36, T. 2 N., R. 2 E. It is the only known occurrence

in the map area. The pink, well-lithified conglomeratic quartz sandstone is slightly calcareous and forms subdued outcrops along the top of the ridge. Pebbles within the conglomeratic portions range up to one half inch in diameter and include volcanic rock types.

No formal name for the beds has received general recognition. They have been variously called Bozeman lake beds, Loup Fork, Madison Valley beds, Bozeman Formation, and Madison Valley Formation. Dorr (1956, p. 62-74) studied vertebrates from the unit at a locality 14 miles south of the mapped area, and concluded that most of the beds are latest Miocene and possibly in part early Pliocene. A mastodon jaw, genus Serridentinus, found during the construction of Interstate 90 two miles northwest of Manhattan, was examined by members of the Department of Earth Science, Montana State University, and found to be of probable mid-Pliocene age. On the basis of this evidence, the beds are tentatively assigned late-Miocene to mid-Pliocene age.

Travertine

A small deposit of undeformed limestone is present in sec. 27, T. 2 N., R. 3 E. It is the only known occurrence of such material in the map area.

The travertine is a buff-white, vuggy, fine- to medium-crystalline limestone. Bedding and banding are weak and irregular. Weathered surfaces are rough and pitted, ranging in color from pale yellow and tan to gray and white. Bedding ranges from platy (averaging 0.25 inches thick)

up to medium bedding about one foot thick. A trace of shaly to silty, platy float material is present along the top of the ridge, but it is not certain that it is related to the limestone. Scattered rounded gravels are also present, but their relationship to other gravels and the limestone is also unclear.

The travertine occurs perched on the shoulder of the second flat-topped ridge west of Nixon Gulch and capping the small but conspicuous knob directly north of the bridge across the Gallatin River. It rests with angular unconformity on the dipping strata of the Precambrian LaHood Formation and dips 2 degrees to the south. The limits of the deposit are difficult to distinguish, but it appears to flank, and at least partially encircle the ridge. It is most distinctive on the east-facing slope.

Conclusive interpretation of this deposit is central to the understanding of the Cenozoic geology of the Horseshoe Hills and Gallatin valley. It is quite possible that the deposit is related to such diverse features as the calcite-filled tensional faults to the north, to pediments surrounding the Gallatin Valley, to one or more of the various gravel deposits, and/or to the middle Tertiary tuffaceous deposits south of the Gallatin River. Resolution of the problem awaits detailed geomorphic work in the Gallatin Valley and adjacent Horseshoe Hills, and geochemical work on the travertine and calcite-filled faults.

Because there is no apparent reason for selective preservation at this location only, it is thought that the deposit must have been very

local. The lithology suggests spring deposition, and this is further supported by the calcite-filled faults that parallel the upper part of Nixon Gulch. It is quite possible that these fractures fed calcite-bearing springs. Hot springs are common in the region and were undoubtedly more prevalent during volcanic episodes earlier in the Cenozoic. Lack of deformation indicates that the deposit is post-Laramide, and close correspondence to present-day topography suggests that it is Quaternary. An alternative explanation is that the limestone dips beneath, and forms the basal unit of, the Mid-Pliocene deposits south of the Gallatin River, but this seems less probable in light of existing evidence. Therefore, in the absence of more extensive work, Quaternary age is tentatively assigned to the deposit.

Cemented Gravel

Gravels of this category are exposed in three locations: in a cliff facing the Gallatin River floodplain in the NE $\frac{1}{4}$, sec. 16, T. 2 N., R. 2 E.; on a steep slope facing Cottonwood Creek in the NE $\frac{1}{4}$, sec. 23, T. 2 N., R. 2 E.; and along the west side of the small southward-draining gulch in south-central sec. 19 and north-central sec. 30, T. 2 N., R. 4 E. At the latter two locations the gravels are almost certainly preserved by downfaulting (the fault along the western edge of sec. 13, T. 2 N., R. 2 E., and the north-south trending fault in central secs. 19 and 30, T. 2 N., R. 4 E., respectively), and it is possible that structural downwarping or faulting has preserved the deposit along the Gallatin

River. It seems probable that other similar deposits are present within the map area, but remain undiscovered due to lack of exposure.

The gravels are composed of poorly-sorted, sub-angular to sub-rounded pebbles averaging about one and one-half inches in diameter. Widely scattered cobbles range up to 14 inches in diameter. Limestones derived from the Paleozoic formations are predominant, although some quartzites from the Paleozoic and Mesozoic section are also present. No recognizable Precambrian clasts were found. The matrix is poorly sorted silty and sandy calcareous material of a tan-gray color. Stratification is conspicuous, although irregular and highly lenticular. Consolidation is adequate to form cliffs locally, but most of the rock can be broken with the hands. It is the most strongly lithified gravel deposit in the map area. The beds tilt up to 7 degrees. They were not mapped.

Poor sorting, highly lenticular bedding, and locally derived constituents suggest that the deposits are fanglomerates. Induration suggests that the gravels may be older than other less well indurated gravels of the area (excepting the high-level gravel), although this is by no means conclusive evidence. Late- or post-Laramide, pre-normal faulting age is indicated by relatively mild deformation and down-faulted position of the beds. Should the age of the gravels be established by future work, and if it could be conclusively shown that they are down-faulted, the age of late-stage faulting could be more closely pinpointed. It seems unlikely that these gravels are older than the late Miocene-early Pliocene age assigned to the nearby gravels of the Madison Bluffs

area (discussed under Tuffaceous Deposits).

Loess

Loess is exposed in many places in the southern part of the map area. All loess deposits are stabilized by vegetation at present. Good examples are along the road in SE $\frac{1}{4}$, NW $\frac{1}{4}$, sec. 25, T. 2 N., R. 2 E.; along the road at the top of the hill in SE $\frac{1}{4}$, sec. 27, T. 2 N., R. 3 E.; and in the valley bottom below the towering limestone cliff in south-central sec. 23, T. 2 N., R. 3 E. Numerous other sites exist. Loess deposits are not mapped.

The material has the lack of stratification and ability to stand in a vertical slope characteristic of loess. However, sorting is poor for a windblown deposit. The sediment is a light buff color. The predominant constituent is silt size quartz, with some grains ranging up to 0.25 mm. in diameter. A low, but conspicuous clay fraction is present. The material is highly calcareous. Small amounts of ferromagnesian minerals, magnetite, and mica are present. Deposits mantle areas topographically favorable for present day eolian deposition. Thicknesses appear to average 5 to 15 feet, and possibly range up to 50 feet.

The poor sorting of the sediment seems to indicate a local source. The most probable source area is the nearby widespread floodplain at the confluence of the Madison, Gallatin, and Jefferson Rivers in the Three Forks vicinity. Because the material is undeformed and is not overlain by any other deposit, it is thought to be Quaternary.

Older Alluvium

Sediments of this category occur in two situations: first, as low terraces flanking the Gallatin River floodplain, and second, mantling the bottoms of the wider valleys in areas away from the rivers. Deposits of the latter type are not mapped.

Deposits of older alluvium of the river terrace type are present in two places: a broad area south and southwest of the Gallatin and West Gallatin River floodplains, and a smaller area northeast of the Gallatin River floodplain northwest of Logan. These deposits are mapped primarily on the basis of their physiographic characteristics. Typical examples of older alluvium of the second type are located along the southeast side of Cottonwood Gulch in the vicinity of Lockhart Ranch in secs. 18, 17, 8, and 9, T. 2 N., R. 3 E., and veneering the valley bottom in the northwestern quarter of sec. 15, and the eastern half of sec. 16, T. 2 N., R. 3 E. The limits of these deposits are poorly defined, precluding mapping, although cultivated areas correspond closely.

Older alluvium present as river terraces along the Gallatin River consists of sub-round to round, somewhat flat, pebbles and cobbles ranging up to 8 inches in diameter in a matrix of coarse sand and fine gravel. Bedding is indistinct, but imbricate orientation of clasts is apparent. Flow direction parallel to the present Gallatin River is indicated. Clasts derived from the basement and volcanic rocks of the Gallatin River drainage are predominant. Mafic lithologies are somewhat rotten, all others are quite solid.

Older alluvium in valleys in the Horseshoe Hills is seen only as float consisting of locally derived sub- to well-rounded limestone derived from the Paleozoic formations, with some quartzite and igneous rock in valleys receiving debris from outcrops of those rock types. Float material ranges from 2 to 10 inches in diameter.

Because of their close physiographic relationship to the present day drainage system, deposits of this category are thought to be Quaternary.

Recent Alluvium

Recent alluvium is mapped in the floodplains of the Madison, Gallatin, East Gallatin and West Gallatin Rivers. Recent stream deposits within the Horseshoe Hills are not mapped.

Recent alluvium in the river floodplains is identical to the older alluvium of the river terraces except that particle size seems to be slightly smaller. The two types are differentiated physiographically. Within the semi-arid Horseshoe Hills stream, action is a minor process, in comparison to stream activity of the past, and Recent stream deposits are relatively insignificant. All material is locally derived. It is predominantly gravel, although sizes range from silt and clay through boulder. Clasts are generally sub-rounded. Stratification is weak, showing effects of torrential deposition. The deposits approximate the present floodplain width, in general 10 to 20 feet, and probably do not exceed 10 feet in thickness.

GEOMORPHOLOGY

Late in Tertiary time widespread areas in the vicinity of the Horseshoe Hills had been buried and reduced to low relief (Robinson, 1963, p. 113 and McMannis, 1955, p. 1426). Dissection and exhumation with intermittent partial reburial have been the dominant physiographic processes since that time. Continued fault movement has also contributed to the shaping of the landscape.

The area has been effectively etched by erosion. The correlation between rock resistance and erosion patterns is very close. Limestone forms the boldest ridges, sandstone and quartzite form weaker ridges, interbedded shale and thin-bedded limestone forms steeper slopes, and shales and igneous sills form gentle slopes and valley bottoms. Solifluction and deflation have been intermittent interstream erosive processes.

The landscape has reached maturity in the erosion cycle. The drainage is moderately well-integrated, divides are sharp, and the land is generally in slope. A medium-coarse drainage texture has developed.

The only perennial streams are the East Gallatin, Gallatin, and Missouri Rivers. With the exception of streams in the vicinity of springs, drainages heading in the map area are dry throughout the year except during the one- or two-week spring runoff period. With the exception of the through-flowing streams, the most extensively developed drainage systems are third order, of which there are two examples, Nixon and Cottonwood Gulches.

Well-developed trellis drainage patterns are predominant in the map area, although some areas show dendritic patterns. It is not surprising that the former is closely related to areas of strongly folded sedimentary rock whereas the latter corresponds to areas of essentially flat-lying, non-resistant Tertiary sediments.

A number of small irregular surfaces have been developed just north of the Gallatin and East Gallatin Rivers. They are primarily erosional, and in general have a thin loess, gravel, or, in one area, travertine veneer. Cultivation is extensive on these surfaces. No consistent level or levels of gradation could be established, although widespread surfaces are present in adjacent areas.

Fault scarps are present in several places. In each case the faults are high angle, transverse structures. Probable Quaternary movement is indicated by the homogeneity of lithology on the adjacent faces of the fault blocks. Good examples are the fault near the eastern border of the map in secs. 8 and 17, T. 2 N., R. 4 E., where the relief between the two sides of the fault is 300 to 400 feet; and the fault in secs. 12 and 13, T. 2 N., R. 2 E. A small graben structure is developed between the two sub-parallel faults in secs. 17 and 20, T. 2 N., R. 3 E. These topographic features can only be explained as fault scarps because the beds are not sufficiently different in resistance to produce fault-line scarps.

IGNEOUS GEOLOGY

All igneous rocks of the area are intrusive and occur as sills. They are described as three units. Structural relationships are further described in the section on structural geology. Limited areal extent and poor exposure of the igneous outcrops precludes mapping them, although the position of intrusive zones is indicated on the map.

Specimens appearing in hand specimen to be representative were collected from each of the units, thin sections were made, and petrographic analyses performed. As a detailed petrologic study was not a major objective of this thesis, only general descriptions are included here.

Microscopic Description

Unit 1 This sill zone is located within the basal Colorado Group, a few feet stratigraphically above the "gastropod limestone" of the Kootenai Formation. It is present at all exposures of that horizon within the map area. The thickness of the zone appears to be up to 200 feet, and individual sills up to 30 feet thick were observed.

<u>Constituent</u>	<u>Percentage</u>	<u>Description</u>
Plagioclase	65%	An ₅₀ (maximum extinction angle 28 degrees as determined on combined Carlsbad-Albite twins); mostly lath-like Carlsbad pairs; faint to strong zoning; partially altered to sericite (?) and calcite (?); subhedral to anhedral matrix grains.
Augite	33%	Extinction angle of 40 degrees with cleavage traces, symmetrical with crystal outlines; occurs as euhedral phenocrysts to 5 mm.; contains fine subhedral magnetite grains; minor amounts altered to amphibole and biotite; twinning common.

Unit 1 (con't)

<u>Constituent</u>	<u>Percentage</u>	<u>Description</u>
Biotite	1%	Pseudouniaxial negative; concentrated in areas of fine-grained alteration material; pleochroic orange to dark brown.
Magnetite	1%	Anhedral, concentrated in areas to 0.5 mm. long; randomly dispersed throughout the rock.
Muscovite	trace	Intimately associated with biotite in fine-grained patches.

Texture: Phaneritic porphyry, diabasic texture

Rock name: Andesite Porphyry

Unit 2 This sill zone is exposed only in the Cottonwood Section. It intrudes rocks of the Amsden Formation and appears to be intimately related to thrust faulting. The zone is up to several hundred feet in thickness, with individual sills ranging up to 50 feet thick.

<u>Constituent</u>	<u>Percentage</u>	<u>Description</u>
Plagioclase	80%	An ₄₁ (?) (determined by the Michel Levy Method, but questionable because of extensive alteration); grains up to 2 mm. long; larger resorpted subhedral phenocrysts are faintly to strongly zoned and highly altered; smaller matrix grains average 0.3 mm., show Carlsbad twinning, moderately altered; clay and calcite-chlorite are the principal alteration products, also some sericite and hematite staining.
Augite	18%	Euhedral phenocrysts up to 3 mm. long; extinction 39 degrees; characteristic twinning with some twin seams; magnetite present as tiny inclusions and concentrated along grain borders.
Biotite	1%	Pleochroic, dark gray-green to medium red-brown color obscuring birefringence; grains average 0.2 mm. long.

Unit 2 (con't)

<u>Constituent</u>	<u>Percentage</u>	<u>Description</u>
Magnetite	1%	Subhedral to anhedral; dispersed throughout the matrix, within augite phenocrysts, and along augite grain boundaries; grains range up to 0.3 mm., average 0.1 mm. in diameter.

Texture: Phaneritic porphyry, diabasic texture

Rock Name: Andesite Porphyry

Unit 3 This sill zone intrudes the Mowry-Thermopolis(?) equivalent of the Colorado Group. Thickness of the zone reaches several hundred feet along the bottom of Cottonwood Gulch in secs. 13 and 24, T. 2 N., R. 2 E., but elsewhere it is very thin, and in places, possibly absent.

<u>Constituent</u>	<u>Percentage</u>	<u>Description</u>
Plagioclase	82%	An ₃₅ (?) (determined by the Michel Levy Method, but questionable because of extensive alteration); grain size up to 2 mm.; larger resorpted subhedral phenocrysts zoned, moderately to highly altered, and somewhat crushed; subhedral matrix plagioclase averages 0.3 mm., moderately altered, Carlsbad twins common; alteration principally to clay with some sericite and hematite staining.
Augite	15%	Extinction angle 40 degrees; occurs as euhedral phenocrysts up to 4 mm. long; grains incorporate fine magnetite grains; characteristic twinning.
Biotite	2%	Orange-brown pleochroic grains up to 0.3 mm. long, birefringence obscured by dark color.
Magnetite	1%	Subhedral grains up to 0.2 mm. in diameter; primarily in matrix, but scattered fine grains within augite phenocrysts

Texture: Phaneritic diabasic porphyry

Rock Name: Andesite Porphyry

The rock classification of Travis (1955, p. 3-11) was followed in naming the rocks. The similarity of the three specimens studied suggests that they may be closely related genetically. However, no positive conclusion is warranted on the basis of this brief study.

STRUCTURE

Tectonic Setting

The map area lies near the juncture of two major elements of regional structure: the northern edge of the Wyoming Shelf of Sloss (1950, p. 428) and the Montana Disturbed Belt of Robinson (1959, p. 34-36). It is located within the Batholithic Province of McMannis (1956, p. 1802-1803 and Fig. 1), just north of the boundary with the Basement Province (McMannis, 1965, p. 1802-1803 and Fig. 1), which corresponds to the Montana portion of the Wyoming Shelf.

Sloss (1950, p. 428) characterizes the Wyoming Shelf as "...a stable area of slow subsidence and correspondingly slow deposition." In southwestern Montana it is characterized by extensive exposures of pre-Belt metamorphic rock. Structural features of the area show conspicuous west-northwest alignment: the Nye-Bowler Lineament (Wilson, 1936), the north flank of the Beartooth and Madison Ranges, and numerous high-angle faults. The northern boundary (with the Batholithic Province) is the zero edge of the Belt Series. According to McMannis (1955, p. 1416) the area has been dominantly positive and generally stable.

As defined by Robinson (1959, p. 34-36), the Disturbed Belt is "...the variably broad sinuous zone of intricately folded and faulted rocks that stretches for more than 350 miles along the eastern front of the Northern Rocky Mountains in southern Alberta and western Montana." The belt is marked by long, parallel, linear ranges trending a little

west of north. West-dipping thrust faults and asymmetric folds are characteristic. Despite the intensity of crustal shortening, basement metamorphic rocks are not brought to the surface, except at one small area in extreme southwestern Montana. Therefore, throughout nearly all of Montana this deformation was shallow-seated. In west-central Montana the Disturbed Belt curves markedly to the southwest and ends abruptly at the Three Forks Basin. However, it picks up again to the southwest and continues southward into Idaho. No known thrust faults occur in the metamorphic rocks to the south of the Three Forks Basin, although it is possible that there were thrusts in the sedimentary rocks that once covered them.

The Batholithic Province, of which the map area is a part, is characterized by numerous intrusives, a thick Belt sedimentary sequence, Cretaceous and Cenozoic extrusives, many Cenozoic non-marine basin deposits, and exceedingly complex structure (McMannis, 1965, p. 1803). These characteristics are all displayed in or near the study area.

The southern boundary of the Batholithic Province, located within a few miles to the south of the thesis area, has been a long-standing tectonic boundary. Sloss (1950, p. 430-431) and McMannis (1963) show that it was the southern, partially fault-controlled, edge of the Belt embayment. Andrichuk (1951, p. 2384 and Fig. 9) shows that a similar pattern of positive and negative areas existed during the Devonian. McMannis (1955, p. 1416) mentions the existence of a partially overlapping trough during the Mississippian. The line is

the site of the present day Beartooth, Gallatin, and Madison mountain fronts and is aligned with the westward projection of the Nye-Bowler lineament. Various workers have suspected and found a variety of evidence for large-scale faulting along the zone: the Ross Pass fault zone of McMannis (1955), the Central Park Fault of Hackett, and others (1960, p. 50-53), the Willow Creek Fault of Robinson (1961, p. 1005). These data are supported (though not proved) by recent geophysical work (Davis, and others, 1965). Thus there has been a differentially mobil east-west belt throughout decipherable geologic history, with the relatively stable and positive block to the south.

As mentioned above, linear features of the northern part of the Montana Disturbed Belt curve to the southwest near its southern extremity and appear to merge with the east-west lineament beneath the Three Forks Basin. The thick sediments of the southern end of the Disturbed Belt, including those of the study area, were pushed westward along, and draped against, the stable Wyoming Shelf block. During the beginnings of the Laramide Orogeny the ancestral Bridger Range developed as a large northeast-plunging anticlinorium in the area of the present Bridger Range and southeastern part of the Horseshoe Hills (see Fig. 1). The Precambrian core of this anticline, located directly southeast of the mapped area, provided a buttress against which the sedimentary sequence of the northwest limb (including the area of this study) were pushed, folded, and ultimately thrust. The dominantly northeast-southwest structural trends of the mapped area are a direct result of that

situation.

Local Structure

Introduction

For purposes of organization of description, the map area is subdivided into four sections: the Green Thrust Section, the Cottonwood Section, the Central Folded Section, and the East Gallatin Section. The Green Thrust Section includes all of the mapped area northwest of the Green Thrust (herein named, see Plate I) and the unnamed thrust fault in secs. 15, 11, and 12, T. 2 N., R. 2 E. The Cottonwood Section includes all of the area southeast of the Green Thrust to the top of the Mission Canyon Ridge southeast of Cottonwood Gulch. The central Folded Section encompasses the area between the Cottonwood Section and the western rim of Nixon Gulch. The East Gallatin Section includes the remainder of the mapped area; that is, all of the area east of the west rim of Nixon Gulch. These structural divisions are shown in Figure 5.

Green Thrust Section

This section is characterized by broad folds which become tight and isoclinal near the leading edge of the thrust. There is relatively little faulting other than the thrust faults.

The major structure is the southwest-plunging syncline that exposes the Mission Canyon Limestone in its core. Dips on the flanks of the syncline are low-- 20° to 30° except in the vicinity of the

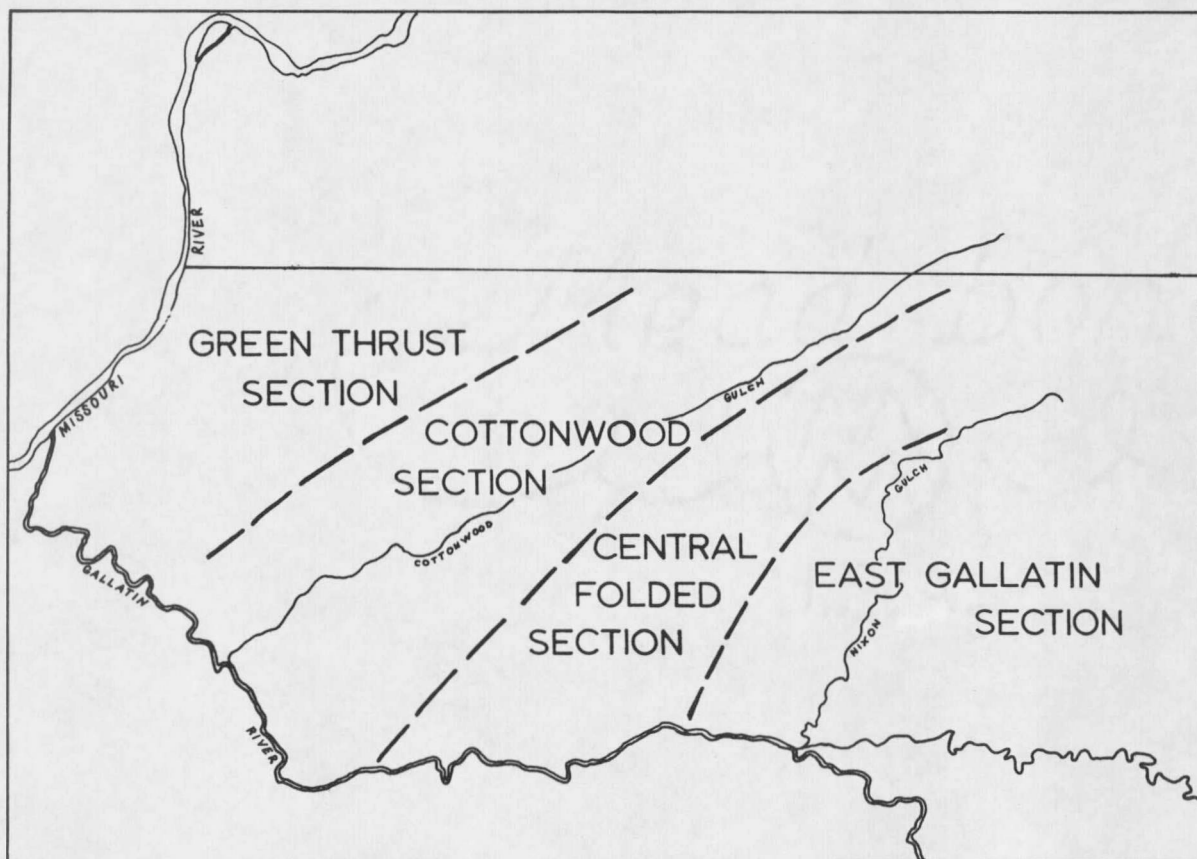


Figure 5 - Index Map showing structural divisions:
North half, Manhattan Quadrangle

Trident Thrust (herein named, see Plate I). The southwestern end of the syncline is largely masked by surficial deposits. In that area contacts are inferred. A few high-angle, transverse faults cut the syncline. Displacement on them is small and largely vertical. The southwest-plunging anticline to the north is a fold of equal magnitude, and shares a common limb. Most of that structure lies to the north of the mapped area.

To the southeast of the broad syncline described above, within the Jefferson Limestone, dips become much steeper. Because of the uniformity of dip and the lithologic monotony of the Jefferson, the structure is difficult to decipher, but it appears to consist of several isoclinal folds, possibly in part thrust faulted. Along the strike to the northeast the high-angle transverse fault located in secs. 5 and 6, T. 2 N., R. 3 E., and sec. 31, T. 3 N., R. 3 E. exposes lower beds within the same structure. At this location beds of the Pilgrim Limestone are folded into a syncline-anticline-syncline pattern, sharing common limbs.

Downsection from the base of the Jefferson, the higher formations of the Cambrian sequence are exposed to the edge of the thrust sheet. Dips are low and attitudes rather irregular, suggesting perhaps, the close proximity of the underlying thrust plane.

The major thrust faults of the section are the Trident thrust and the Green thrust (see Plate I). In each case, maximum displacement appears to be at least one-half mile, and possibly as much as several

miles. The Trident thrust superimposes a broad band of northwestward dipping Paleozoic and Mesozoic rocks upon the above-described broad syncline-anticline structure. Rocks at the leading edge of the Trident thrust include the Jefferson, Three Forks, Lodgepole, and Mission Canyon formations. Cambrian, Devonian, and Mississippian rocks of the subthrust plate disappear beneath the Trident thrust plate.

The Green thrust is well exposed in the map view, particularly on air photos, but no cross sectional exposures of the fault plane were found. The fault's sinuous trace is suggestive of low dip, perhaps as low as 20 degrees. It is not traceable to the southwest in the wide Jefferson outcrop band. It may merge with the unnamed thrust to the southwest.

The unnamed thrust fault is secs. 15, 11, and 12, T. 2 N., R. 2 E. dips about 35 degrees to the northwest. It is well exposed near the center of sec. 11 and in west-central sec. 12. It is traceable only a short distance to the northeast. It may merge with the Green thrust or it may continue within the Jefferson to the unnamed northeast-trending thrust located in sec. 1, T. 2 N., R. 2 E., sec. 6, T. 2 N., R. 3 E., and sec. 31, T. 3 N., R. 2 E. That thrust is poorly exposed where Jefferson beds are in fault contact, but to the northeast beyond the mapped area in sec. 31, Cambrian beds on the leading edge of the thrust plate render the fault more readily traceable.

Thrusts of the mapped area show no evidence of having been folded. In the absence of any other evidence to the contrary, it is assumed

that as deformation progresses, folding became increasingly tight until thrusting developed. This places folding before thrusting in the sequence of structural events.

Cottonwood Section

In its most general aspect, the Cottonwood Section is structurally a large asymmetric syncline, herein named the Cottonwood syncline (see Plate I). Older literature referred to the structure as the Cottonwood Isocline (Peale, 1893). The section is characterized by gently southwest-plunging asymmetrical folds with many dips 50 to 90 degrees to the northwest. At least one thrust fault is present in the section. Numerous north-south oriented, high-angle, small displacement transverse faults are also characteristic.

Beds of the northwest limb of the syncline, directly southeast of the Green thrust, are vertical to overturned. High-angle, strongly aligned transverse faults are particularly common along this limb.

The Beacon thrust (herein named, see Plate I) is the only thrust mapped within the Cottonwood Section. It extends for about 3 miles along the base of the southeast side of the ridge that supports the aviation beacon situated on the mutual boundary of secs. 34 and 35, T. 3 N., R. 3 E. The fault closely parallels the adjacent beds. It is not well exposed, but is inferred from the stratigraphic sequence and the truncation of beds apparent on air photos. Evidence of the faulting may have been obscured in part by intrusive activity.

In the area directly to the southeast of the Beacon thrust is a small, but sharply folded anticline. It plunges at variable low angles to the northeast and southwest throughout most of its length, but in the area west of Lockhart Ranch it assumes a steep plunge to the southwest. In that area the fold at least in part accomplishes the crustal shortening achieved by the Beacon thrust farther along strike to the northeast. In places the core of the anticline is composed of the massive Mission Canyon Limestone. Traces of individual beds suggest that one or both contacts of the limestone core could be thrust-faulted, but contacts are not exposed, and in the absence of direct evidence of thrusting, the simpler fold solution was depicted on the map and cross sections. If thrusting is present, displacement is very small.

Outcrops are widely scattered in the bottom of Cottonwood Gulch as a result of the low relief, masking by stream deposits, and non-resistance of the upper Kootenai and Colorado rocks. The synclinal fold plunges very gently to the southwest. The wide trough of the southwestern part of the Cottonwood syncline is interrupted by a minor anticlinal crest, the possible southwestward extension of the small anticline directly southeast of the Beacon thrust. This produces a southwest-plunging syncline-anticline-syncline fold system within the trough of the southwestern portion of the Cottonwood Syncline. It is apparent from the outcrop pattern that the dying out of the anticline to the southwest results in widening of the syncline in that direction.

The Kootenai-Colorado contact in the northwestern limb of the syncline in the vicinity of Lockhart Ranch may be in part a thrust fault contact. However, if thrusting is involved displacement is not detectable, and for that reason the contact is not mapped as a fault contact.

The southeastern limb of the Cottonwood syncline is structurally routine, with dips ranging very close to the average value of 50 degrees. A few transverse high-angle faults cut the competent middle Paleozoic formations.

Intrusives of the Cottonwood Section

The three sill zones of the mapped area are present within, and largely confined to, the Cottonwood Section. Petrography of the intrusives has been described in the section on igneous geology. Their structural relationships are described here.

In the vicinity of the Beacon Thrust the Amsden Formation has served as host to a thick andesitic sill zone. Contacts are generally obscure in the non-resistant sills and the host rock, but the concordance of those contacts exposed suggests injection as the method of emplacement. Pre-folding age of emplacement is demonstrated by the presence of sills in both limbs of the small but steep anticline directly southeast of the trace of the Beacon thrust, and is also suggested by the lack of conspicuous phacolithic development along the crest of the anticline.

Two andesitic sill zones were observed within the Colorado Group.

The upper, located in SW $\frac{1}{4}$ sec. 13 and NW $\frac{1}{4}$ sec. 14, T. 2 N., R. 2 E., is of very limited areal extent. Sills ranging up to 20 feet thick intrude a stratigraphic thickness of several hundred feet. The sills appear to be completely concordant, and forcefully injected. Elsewhere the zone is very thin, and in places may be absent.

The second, and lower sill zone is located just above the "gastropod" limestone that marks the upper contact of the Kootenai Formation. The sills were found at all exposures of that horizon. The sill zone is usually marked by reddish, sagebrush-covered soils, hardened and baked sandstone layers, and bleached "gastropod" limestone. The zone is unusually widespread and stratigraphically consistent, and has been folded with the Mesozoic sequence. It is broken by post-compressional faulting, most conspicuously in SW $\frac{1}{4}$ sec. 12, T. 2 N., R. 3 E. The sill zone is approximately 200 feet thick, with individual sills up to 30 feet in thickness.

On the basis of petrographic similarity, and in the absence of evidence to the contrary, it is assumed that the igneous rocks of the mapped area are genetically related. The same assumption has been made in the adjacent Three Forks quadrangle. Robinson (1963, p. 98-102) reports "strong inference" that the much greater diversity of Three Forks quadrangle intrusives (including some quite similar to those of the southwestern Horseshoe Hills) are genetically related. Assuming, then, that the sills are of the same vintage, they are no older than

the Late Cretaceous rocks which are the youngest rocks intruded. Folding of the sills indicates that they were emplaced before folding of the area. This places the time of intrusion as Late Cretaceous or possibly earliest Tertiary.

Central Folded Section

Intricate folding with crestral faulting is characteristic of this section. Figure 2 is an aerial view of the Central Folded Section. The essence of the structure is a northeast-striking, northeast-plunging fold system consisting from northwest to southeast of two mildly faulted anticline-syncline pairs. The number of folds increases to the southwest and their amplitude decreases in that direction.

The faults of this section follow closely the crestral planes of all of the tighter folds. These crestral faults appear to be in part the breaking of the tightly folded beds, but along the trace where deformation was more intense they show reverse or thrust displacement. Examples are the fault NE $\frac{1}{4}$ sec. 30 and SW $\frac{1}{4}$ sec. 20; the fault in secs. 21, 16, 15, 10, and 11; and the fault in secs. 16 and 10, T. 2 N., R. 3 E. It is thought that these faults are indicative of less intense crustal shortening than in areas farther to the northwest where full scale thrust faults are developed. It is suggested that the faults were initiated as breaks resulting from tight folding in the fold noses, and that where deformation was extensive enough, these breaks developed into thrust displacements. Had crustal shortening continued, they

could have developed into full scale thrust faults.

The change in number and amplitude of folds along the structural trend is thought to be the result of two factors: the greater competency of the upper part of the Paleozoic section (Jefferson through Mission Canyon) than in the formations above and below, and the proximity of a basement buttress provided by the core of the ancestral Bridger Range to the southeast. That part of the Central Folded Section near the Gallatin River was folded into many small folds as the incompetent beds were pushed against the nearby buttress. Farther northeast in the Central Folded Section, however, the more competent massive carbonate formations achieved approximately equal crustal shortening as broader folds with greater amplitudes. Fault displacement is apparently greater, and individual faults more extensive, than in areas to the southwest.

East Gallatin Section

The East Gallatin Section, in the southeastern part of the map area, is characterized by its lack of large fold structures and its many transverse, high-angle faults. Dips range from 30 to 55 degrees and are generally to the north.

Four long faults, or fault zones, cross obliquely to the structure of the section. They correspond with gulches and saddles in the major ridges, erosion having exploited the zones of weakness. Because of their topographic situation, the fault planes are poorly exposed in most places. Fault traces are mapped primarily on the basis of displace-

ments in the outcrop pattern and topographic characteristics. Faults in the upper Nixon Gulch area are accentuated by deposits of banded, coarsely crystalline calcite. These calcite "dikes" range up to nearly 50 feet in thickness. Development of crystalline calcite normal to the fault plane suggests calcite filling of a widening fracture. The tensional faulting thus suggested is late stage, as evidenced by the lack of any subsequent deformation of the faults. The nature of the displacement along these faults is variable: apparent movement of the various faults shows no consistent pattern, further suggesting primarily tensional movement. With the exception of the fault in the upper end of Nixon Gulch, apparent displacements are not great.

The relatively high separation of the fault at the upper end of Nixon Gulch is thought to be due to the proximity of the tightly folded synclinal nose to the northwest. The apparent strike-slip component is approximately 500 feet. The stratigraphically consistent low Colorado sill is markedly offset by the fault.

As in the Central Folded Section, the Cambrian formations are more intricately folded than the younger formations, probably as a direct result of the lack of any thick, massive, competent unit in the sequence. In contrast to the Central Folded Section, however, short high-angle faults are predominant and folding is markedly disharmonic. Conspicuous folds in the Cambrian formations die out upsection. There is no evidence in formations above the Lodgepole of the half dozen or so folds present at deeper stratigraphic levels. The short, large

displacement faults present within the Cambrian sequence contribute to this pattern. In general, although displacement is large, these faults do not penetrate more than one competent formation.

Summary of Structural History

The following sequence of events is derived from the foregoing discussions of stratigraphy and structure:

(1) Late in the Precambrian a thick sequence of predominantly clastic material (LaHood Formation) derived from a nearby fault uplift to the south was deposited unconformably on the metamorphic basement in an east-west trending embayment.

(2) A major erosional interval followed, during which the sediments were warped, very slightly metamorphosed, and deeply eroded.

(3) Beginning in the Middle Cambrian, the Paleozoic-Mesozoic sequence was deposited. As a part of the area of the old Belt embayment, the map area remained strongly negative through most of the Paleozoic and again in the Cretaceous. The Wyoming Shelf to the south was weakly positive during that time. In the vicinity of the southwestern Montana-Idaho border, an arch existed as a source area until the Mississippian, at which time it became strongly negative.

(4) During the Late Cretaceous or early Tertiary, but prior to deformation, sills were emplaced.

(5) During the Late Cretaceous and early Tertiary, major deformation (the Laramide Orogeny) took place. Initial folding accompanied by faulting culminated in thrust faulting as deformation became increasingly intense.

(6) Erosion and continental deposition accompanied and followed deformation, and as compressional stresses were relaxed, tensional faulting developed. Earth movements, such as the 1925 "Montana Earthquake," which was centered just north of the mapped area, and location of epicenters along the Central Park fault directly south of the area indicate that this activity continues to the present.

ECONOMIC GEOLOGY

Mineral resources of the southwestern Horseshoe Hills are restricted to non-metallics. Minerals exploited in the area are all widely available in southwestern Montana, so production is determined primarily by ease of acquisition and local demand.

By far the most important economic interest in the mapped area is the cement industry. In 1908 the Ideal Cement Company erected a cement plant at Trident and initiated quarrying operations in that vicinity. The plant is now relatively old and small, but its advantageous physical situation enables it to remain competitive. Economic advantage is derived from the downhill haul from the quarry floor to the mill, the optimum chemical content of the rock, and proximity of a railroad mainline.

Rock from the lower part of the Lodgepole Limestone is quarried for the cement-making. The shaly character of this portion of the formation has been advantageous in cement manufacture, because limestone and shale are in optimum proportions (78% CaCO_3) for cement manufacture, and all rock can be taken from one quarry, thereby eliminating the need to mix bulk rock. Magnesium content of the rock is generally well below the prescribed 3 percent maximum. When magnesium content does occasionally become excessive, the bulk rock is cut with sandstone from the lower Kootenai Formation or shale from the lower Colorado Group. Shale in the Lodgepole is not present in adequately large masses to obtain the shale in the main quarry. These sources are

also used on occasion to control color of the product. Purer limestone from higher in the Madison Group is also used as mix to increase the proportion of calcium carbonate in the product and for special types of cement. Calcium carbonate in these rocks ranges up to 96 percent.

Quarrying operations in the Lodgepole Limestone began in the cliff face directly south of the cement plant. In the mid-1950's a second quarry was opened directly east of the plant. By 1966 that source had been largely exhausted, and a third quarry was begun directly southwest of the first quarry. "Pure" limestone from the Mission Canyon is supplied from a quarry 0.6 miles southeast of the plant in west-central sec. 10, T. 2 N., R. 2 E. Sandstone from the Kootenai is quarried about 3.5 miles southeast of Trident in west-central sec. 24, T. 2 N., R. 3 E. The shale pit is located nearby in SW $\frac{1}{4}$ sec. 13, T. 2 N., R. 3 E.

The only other quarrying operation of consequence at the present time is by Kanta Products Inc. of Three Forks. They operate a shale pit directly northeast of the Ideal Cement shale pit in SW $\frac{1}{4}$ sec. 13, T. 2 N. R. 3 E. Shale from the pit is hauled to Three Forks, crushed and burned, and the aggregate thus produced is mixed with cement and molded into cinder blocks. A spokesman for Kanta Products reported that the burned shale aggregate would be suitable as light-weight concrete aggregate if produced in coarser sizes, but no such production is currently carried on due to lack of demand.

Building stone is widely available within the mapped area, but

no production exists at present. The Nixon Gulch fault calcite, described in previous sections, was quarried many years ago, and marketed as "Montana Onyx." Apparently production was terminated due to lack of demand. Several of the formations present in the mapped area could produce attractive building stone, but there is no reason to suspect that such material will be needed.

Sand and gravel present is adequate for local consumption, and several small pits are intermittently operated by farmers and county road crews. Commercial quantities of the material are available closer to populated areas, so it is unlikely that there will be further development of that resource within the mapped area.

Coal was mined in Nixon Basin many years ago, apparently by local residents for their own consumption. Pits were located in NE $\frac{1}{4}$ sec. 12, T. 2 N., R. 3 E., and in NW $\frac{1}{4}$ sec. 6, T. 2 N., R. 4 E. Thin coals of the Colorado Group were exploited. It is unlikely that the deposits will be reopened owing to wide availability of inexpensive coal.

APPENDIX

APPENDIX

Colorado Group Measured Section

Colorado Group section measured with steel tape along the gully in SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 36, T. 3 N., R. 3 E., SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 31, T. 3 N., R. 4 E., and NW $\frac{1}{4}$ sec. 6, T. 2 N., R. 4 E. Upper part of the measured section poorly exposed. Total thickness of Colorado not measured because top of measured section is erosional.

	Thickness of unit (feet)	Cumulative thickness (feet)
Colorado Group		
Cody(?) equivalent		
1. Sandstone, green-brown, dirty, glauconitic, platy to thin-bedded, poorly exposed, forms weak ridge, top of unit erosional at center of syncline...	90	90
2. Covered (dip slope and valley)	145	235
3. Sandstone, dirty green-brown, fine-grained, platy, mostly covered, forms weak ridge.	60	295
4. Covered (dip slope)	148	443
5. Covered (antidip slope)	206	649
6. Covered (top, weak ridge)	101	750
Frontier(?) equivalent		
1. Sandstone, very coarse grained, dirty, "salt and pepper" thin-bedded, glauconitic	9	759
2. Covered, porcelanite float, white, cryptocrystalline to glassy, brecciated and devitrified along fractures	76	835
3. Sandstone, gray, fine-grained, hard, clean, medium-bedded, weathers orange .	15	850
4. Covered, float contains orange sandstone as above	52	902
5. Sandston, white, medium-bedded, "salt and pepper"	6	908
6. Covered, coal and sandstone float, coal pit near top, coal lignitic, shaly . . .	81	989
7. Covered, yellow platy siltstone float . .	100	1089
8. Sandstone, white, quartzose, non-calcareous, massive	8	1097
9. Shale, dark green, blocky, dirty, with some interbedded hard, white, medium-bedded, "salt and pepper" sandstone, interval poorly exposed	168	1265

Frontier(?) equivalent (con't)	Thickness of unit (feet)	Cumulative thickness (feet)
10. Sandstone, white, quartzose, "salt and pepper", hard, in 6 inch beds.	6	1271
11. Covered, with sandstone float, appears to be like unit 12.	120	1391
12. Sandstone, gray, "dirty", medium- grained, calcareous, beds to one foot thick, with some blocky, medium gray, silty shale	21	1412
13. Covered, with very white coarse- grained quartz sandstone float. . . .	70	1482
Mowry(?) and Thermopolis(?) equivalent		
1. Covered, sandstone float as below. . .	59	1541
2. Sandstone, medium gray-green, medium hard, slightly calcareous, platy, fine-grained, locally cross-bedded, metamorphosed near intrusive contact. (6 inch andesitic sill)	20	1561
3. Siltstone, orange, crumbly, with 4 inch layer clean white clay (bentonite?).	5	1566
4. Sandstone, "dirty", "salt and pepper" platy, with gray-green blocky to platy shale	6	1572
5. Covered, sandstone float as below. . .	23	1595
6. Sandstone, green-gray, dirty to clean salt and pepper, non-calcareous, thin-bedded	8	1603
7. Mostly covered, sandstone float as above, with black blocky, very hard shale	75	1678
8. Sandstone, olive yellow, coarse grained, salt and pepper.	10	1688
9. Covered, yellow soil	31	1719
10. Sandstone, green-gray, fine-grained, thin-bedded, inter-bedded with dark shale	22	1741
11. Sandstone, olive green, soft, salt and pepper, thin-bedded to platy, non-calcareous, crumbly, weathers black, coarse-grained	25	1766
12. Shale, black, hard, blocky, non- calcareous, with thin interbedded yellow siltstone layers	41	1807

Mowry(?) and Thermopolis(?) equivalent (con't)

	Thickness of unit (feet)	Cumulative thickness (feet)
13. Siltstone, yellow, platy to blocky, partly covered.	11	1818
14. Sandstone, gray, quartzose, medium- bedded, very calcareous.	6	1824
15. Claystone, olive yellow-green, blocky slightly calcareous, weathers yellow, siltstone in part, with interbedded red hematitic concretionary layers. . .	94	1918
16. Covered, probably like the above interval.	254	2172
17. Shale, dark greenish, silty, weathers orange.	16	2188
18. Covered.	12	2200
19. Shale, as above.	16	2216
20. Shale, green-black, moderately fissile	3	2219
21. Covered, may include sills	16	2235
22. Quartzite, yellow, crossbedded, hard. (6 inch andesitic sill)	3	2238
23. Quartzite, yellowish and pinkish white, crossbedded, as below	1	2239
(14 foot andesitic sill)		
24. Quartzite, pinkish white, crossbedded, thin-bedded, with some siltstone. . .	30	2269
25. Concretionary layers, dark red, hematitic, with siltstone	2	2271
26. Siltstone, gray, weathers yellow, platy to thin-bedded, with minor interbedded quartzite, white, cross- bedded, thin-bedded	22	2293
27. Covered.	5	2298
28. Shale, dark green, blocky, with nodules.	3	2301

Kootenai Formation

"gastropod limestone"

REFERENCES CITED

- Achauer, C. W., 1959, Stratigraphy and microfossils of the Sappington Formation in southwestern Montana, in Billings Geol. Soc. Guidebook 13th Ann. Field Conf.: p. 41-49.
- Andrichuk, J. M., 1951, Regional stratigraphic analysis of Devonian system in Wyoming, Montana, southern Saskatchewan, and Alberta: Am. Assoc. Petroleum Geologists Bull., v. 35, 0. 2368-2408.
- _____, 1955, Mississippian Madison Group stratigraphy and sedimentation in Wyoming and southern Montana: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 11, p. 2170-2210.
- Benson, A. L., 1966, Devonian stratigraphy of western Wyoming and adjacent areas: Am. Assoc. Petroleum Geologists Bull., v. 50, no. 12, p. 2566-2603.
- Berry, G. W., 1943, Stratigraphy and structure at Three Forks, Montana: Geol. Soc. America Bull., v. 54, no. 1, p. 1-29.
- Brown, R. W., 1946, Fossil plants and the Jurassic-Cretaceous boundary in Montana and Alberta: Am. Assoc. Petroleum Geologists Bull., v. 30, no. 2, p. 238-248.
- Condit, D. D.; Finch, E. H., and Pardee, J. T., 1928, Phosphate rock in the Three Forks-Yellowstone Park region, Montana: U. S. Geol. Survey Bull. 795 - G, p. 147-221.
- Cooper, G. A., and others, 1942, Correlation of the Devonian sedimentary formations of North America: Geol. Soc. America Bull., v. 53, p. 1729-94.
- Cressman, E. R., and Swanson, R. W., 1964, Stratigraphy and petrology of the Permian rocks of Southwestern Montana: U.S. Geological Survey Prof. Paper 313-C, 294 pp.
- Davis, W. E. and others, 1965, Bouguer gravity, aeromagnetic, and generalized geologic map of the eastern part of the Three Forks Basin, Broadwater, Madison, and Gallatin Counties, Montana: U.S. Geol. Survey Geophysical Inv. Map GP-498.
- Deiss, C. F., 1936, Revision of the type Cambrian formations and sections of Montana and Yellowstone National Park: Geol. Soc. America Bull., v. 47, no. 8, p. 1257-1342.
- Dorr, J. A., 1956, Anceney local mammal fauna, Montana: Jour. Paleontology, v. 30, no. 1, p. 62-74.

- Dutro, J. T. and Sando, W. J., 1963, Age of certain post-Madison rocks in southwestern Montana and western Wyoming: U.S. Geol. Survey Prof. Paper 475-B, Art. 23, p. B93-94.
- Fenneman, N. M., 1931, Physiography of Western United States: New York, McGraw-Hill, 534 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, 166 p.
- Gutschick, R. C., 1964, Transitional Devonian to Mississippian environmental changes in western Montana in Symposium on Cyclic Sedimentation: Kansas Geol. Survey Bull. 169, vol. 1, 1964, p. 171-181.
- Gutschick, R. C., Suttner, L. J., and Switek, M. J., 1962, Biostratigraphy of transitional Devonian-Mississippian Sappington Formation of southwest Montana, in Billings Geol. Soc. Guidebook 13th Ann. Field Conf., The Devonian System of Montana and adjacent areas-- a symposium, Sept. 1962: p. 79-89.
- Hackett, O. M., and others, 1960, Geology and ground-water resources of the Gallatin Valley, Gallatin County, Montana: U.S. Geol. Sur. Water Supply Pap. 1482, 282 p.
- Hanson, A. M., 1952, Cambrian stratigraphy in southwestern Montana: Montana Bur. Mines and Geol. Mem. 33.
- _____, 1960, Cambrian of the Madison River Valley area in 11th Annual Field Conference Guidebook: Billings Geol. Soc., p. 207-212.
- Harris, W. L., 1966, The stratigraphy of the Upper Jurassic - Lower Cretaceous rocks in the Great Falls - Lewistown Coal Field, central Montana: In Billings Geological Soc. Guidebook 1966, p. 164-177.
- Henbest, L. G., 1956, Foraminifera and correlation of the Tensleep Sandstone of Pennsylvanian age in Wyoming: Wyoming Geol. Assoc., 11th Annual Field Conf. Guidebook, 1956, p. 58-63.
- Holland, F. D., 1952, Stratigraphic details of lower Mississippian rocks of northeastern Utah and southwestern Montana: Am. Assoc. Petroleum Geologists Bull. v. 36, no. 9, p. 1697-1734.
- Imlay, R. W., Gardner, L. S., Rogers, C. P., and Hadley, H. D., 1948, Marine Jurassic formations of Montana: U.S. Geol. Survey Oil and Gas Investigations Preliminary Chart 32.

- Klepper, M. R., and others, 1957, Geology of the southern Elkhorn Mountains, Jefferson and Broadwater Counties, Montana: U.S. Geol. Survey Prof. Paper 292, p. 1-82.
- Knechtel, M. M., Smedley, J. E., and Ross, R. J., 1954, Little Chief Canyon Member of Lodgepole Limestone of Early Mississippian age in Montana: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 11, p. 2395-2400.
- Laird, W. M., 1947, An Upper Devonian brachiopod fauna from northwestern Montana: Journal of Paleontology, v. 21, no. 5, p. 453-59.
- Lebauer, L. R., 1964, Petrology of the Middle Cambrian Wolsey Shale of southwestern Montana, Jour. of Sed. Petrology, v. 34, no. 3, p. 503-511.
- _____, 1965, Genesis and environment of deposition of the Meagher Formation in southwestern Montana: Jour. Sed. Petrology, v. 35, no. 2, p. 428-447.
- Lochman, G., 1950, Status of the Dry Creek Shale of central Montana: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 2200-2222, 10 Figs.
- Lochman-Balk, Christina, 1956, The Cambrian of the Rocky Mountains and southwest deserts of the United States and adjoining Sonora Province, Mexico: 20th International Geological Congress, p. 529-653.
- Lochman, Christina, 1957, Paleoecology of the Cambrian in Montana and Wyoming, chap. 8 in Ladd, H.S., ed., Paleoecology, v. 2 of Treatise on marine ecology and paleoecology: Geol. Soc. America Mem. 67, p. 117-162.
- Lochman, Christina, and Duncan, D. C., 1944, Early Upper Cambrian faunas of central Montana: Geol. Soc. America Spec. Pap. 54.
- Lochman, Christina, and Hu, Chung-Hung, 1962, An Aphelaspis zone faunule from Logan, Montana: Jour. of Paleontology, vol. 36. no. 3, p. 431-41.
- McKee, E. D., and others, 1956, Paleotectonic maps of the Jurassic System: U.S. Geol. Survey Misc. Geol. Inv., Map I-175.
- McKelvey, V. E., and others, 1956, Summary description of Phosphoria, Park City, and Shedhorn formations in western phosphate field: Am. Assoc. Petroleum Geol. Bull., v. 40, p. 2826-63.
- McMannis, W. J., 1955, Geology of the Bridger Range, Montana: Geol. Soc. Am. Bull., v. 66, p. 1385-1430, 5 Figs., 8 Pls.

- _____, 1962, Devonian stratigraphy between Three Forks, Montana and Yellowstone Park, in Three Forks - Belt Mountains Area and Symposium: The Devonian System of Montana and adjacent areas: Billings Geol. Soc. 13th Annual Field Conf. Guidebook, p. 4-12.
- _____, 1963, LaHood Formation-- A coarse facies of the Belt Series in southwestern Montana: Geol. Soc. Am. Bull., v. 74, p. 407-436.
- _____, 1965, Resume of depositional and structural history of western Montana: Am. Assoc. Petroleum Geol. Bull., v. 49, n. 11, p. 1801-1823.
- McMannis, W. J. and Chadwick, R. A., 1964, Geology of the Garnet Mountain quadrangle, Gallatin County, Montana: Mont. Bureau of Mines and Geol., Bull. 43, 47 pp.
- Middleton, G. V., 1961, Evaporite solution breccias from the Mississippian of southwest Montana: Jour. of Sed. Pet., v. 31, no. 2, p. 189-195.
- Moritz, C. A., 1951, Triassic and Jurassic stratigraphy of southwestern Montana: Am. Assoc. Petroleum Geol. Bull., v. 35, p. 1781-1814.
- Peale, A. C., 1893, The Paleozoic section in the vicinity of Three Forks, Montana: U.S. Geol. Survey Bull. 110.
- _____, 1896, Description of the Three Forks sheet, Montana, U.S. Geol. Survey Geol. Atlas, Folio 24.
- Perry, E. S. and Sloss, L.L., 1943, Big Snowy Group: lithology and correlation in the northern Great Plains: Am. Assoc. Petroleum Geol. Bull., v. 27, no. 10, p. 1287-1304.
- Peterson, J.A., 1957, Marine Jurassic of northern Rocky Mountains and Williston Basin: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 3, p. 399-440.
- Rau, J. L., 1962, The stratigraphy of the Three Forks formation, in Three Forks - Belt Mountains Area and Symposium - the Devonian System of Montana and adjacent areas: Billings Geol. Soc. 13th Annual Field Conf. Guidebook, p. 51-66.
- Roberts, A. E., 1961, Insoluble residues and Ca:Mg ratios in the Madison Group, Livingston, Montana, in Geol. Survey Research: U.S. Geol. Survey Prof. Pap. 424-B, p. B294-B296.
- _____, 1964a, Geologic Map of the Mystic Lake Quadrangle, Montana: U.S. Geological Survey, Miscellaneous Geol. Inv. Map I-398.

- _____, 1964b, Geology of the Hoppers Quadrangle, Montana: U.S. Geol. Survey Prof. Paper 475-B, p. B86-B89.
- _____, 1965, Correlation of Cretaceous and Lower Tertiary rocks near Livingston, Montana, with those in other areas of Montana and Wyoming, in Geol. Survey Research: U.S. Geol. Survey Prof. Pap. 525-B, p. B54-B63.
- _____, 1966a, Geology and coal resources of the Livingston Coal Field, Gallatin and Park Counties, Montana: U.S. Geol. Survey Prof. Pap. 526 - A, 56 p.
- _____, 1966b, Stratigraphy of Madison Group near Livingston Montana, and discussion of karst and solution-breccia features: U.S. Geol. Survey Prof. Pap. 526 - B, 23 p.
- Robinson, G. D., 1959, The Disturbed Belt in the Sixteen Mile area, Montana, in Sawtooth-Disturbed Belt area: Billings Geol. Soc., 10th Annual Field Conf. Guidebook, p. 34-40.
- _____, 1961, Origin and development of the Three Forks Basin, Montana: Geol. Soc. Am. Bull., v. 72, p. 1003-14, 2 figures.
- _____, 1963, Geology of the Three Forks quadrangle, Montana: U.S. Geol. Survey Prof. Pap. 370, 143 pp.
- _____, 1967, Geologic map of the Toston quadrangle, southwestern Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I-486, 2 sheets.
- Ruppel, E. T., 1950, Geology of Limestone Hills, Broadwater County, Montana: U.S. Geol. Survey Open File Report.
- Sandberg, C. A., 1961, Widespread Beartooth Butte Formation of Early Devonian age in Montana and Wyoming and its paleogeographic significance: Am. Assoc. Petroleum Geol. Bull., v. 45, p. 1301-1309.
- _____, 1962, Stratigraphic section of type Three Forks and Jefferson formations at Logan, Montana, in Three Forks - Belt Mountains Area and Symposium: The Devonian System of Montana and Adjacent Areas: Billings Geol. Soc. 13th Annual Field Conf. Guidebook, p. 47-50.
- _____, 1963, Dark shale unit of Devonian and Mississippian age in northern Wyoming and southern Montana: U.S. Geol. Survey Prof. Pap. 475-c, p. C17-C20.

- _____, 1965, Nomenclature and correlation of lithologic subdivisions of the Jefferson and Three Forks formations of southern Montana and Northern Wyoming: U.S. Geol. Survey Bull. 1194-N, 18 p.
- Sandberg, C. A., and Hammond, C. R., 1958, Devonian system in Williston Basin and central Montana: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 2293-2334.
- Sandberg, C. A., and McMannis, W. J., 1964, Occurrence and paleogeographic significance of the Maywood Formation of Late Devonian age in the Gallatin Range, southwestern Montana: in Geological Survey Research, 1964, U.S. Geol. Survey Prof. Pap. 501-C, p. C50-C54.
- Sando, W. J. and Dutro, J. T., 1960, Stratigraphy and coral zonation of the Madison group and Brazer dolomite in northeastern Utah, western Wyoming, and southwestern Montana: Wyoming Geol. Assoc. Guidebook, 1960, p. 117-126.
- Scott, H. W., 1935, Some Carboniferous stratigraphy in Montana and northwestern Wyoming: Jour. Geol., v. 43, no. 8, pt. 2, p. 1011-1032.
- Simpson, G. G., 1926, Age of the Morrison Formation: Am. Jour. Sci., 5th Ser., v. 12, p. 198-216.
- Skipp, Betty, and Peterson, Anne D., 1965, Geologic map of the Maudlow quadrangle, southwestern Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I-452, 2 sheets.
- Sloss, L. L., 1950, Paleozoic sedimentation in Montana area: Am. Assoc. Petroleum Geol. Bull., v. 34, no. 3, p. 423-451.
- Sloss, L. L., and Hamblin, R. H., 1942, Stratigraphy and insoluble residues of the Madison group (Mississippian) of Montana: Am. Assoc. Petroleum Geologists Bull., v. 26, no. 3, p. 305-335.
- Sloss, L. L. and Laird, W. M., 1946, Devonian stratigraphy of central and northwestern Montana: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart 25.
- _____, 1947, Devonian System in central and northwestern Montana: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 8, p. 1404-1430.
- Sloss, L. L., and Moritz, C. A., 1951, Paleozoic stratigraphy of southwestern Montana: Am. Assoc. Petroleum Geol. Bull., v. 35, no. 10, p. 2135-2169.

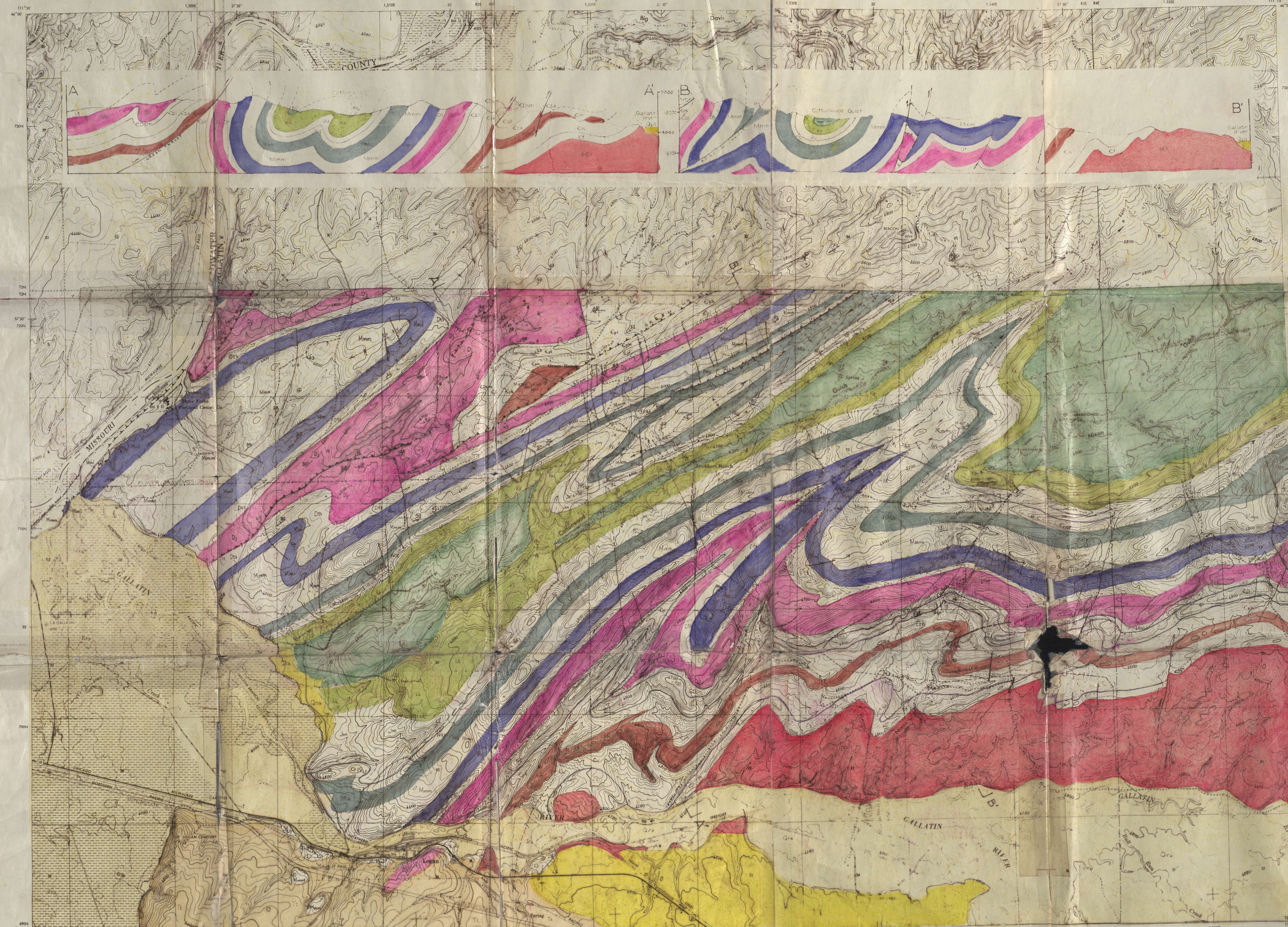
Travis, R. B., 1955, Classification of rocks: Quarterly of the Colorado School of Mines, v. 50, no. 1.

Wilson, C. W., Jr., 1936, Geology of the Nye-Bowler lineament, Stillwater and Carbon Counties, Montana: Am. Assoc. Petroleum Geologists Bull., v. 20, no. 9, p. 1161-88.

Wilson, J. L., 1955, Devonian correlations in northwestern Montana: Billings Geol. Soc., 6th Ann. Field Conf. Guidebook, p. 70-77.

Yen, T. C., 1951, Fresh-water mollusks of Cretaceous age from Montana and Wyoming: U.S. Geol. Survey Prof. Pap. 233-A, p. 1-20.

_____, 1952, Molluscan fauna of the Morrison Formation: U.S. Geol. Survey Prof. Pap. 233-B, p. 21-51.

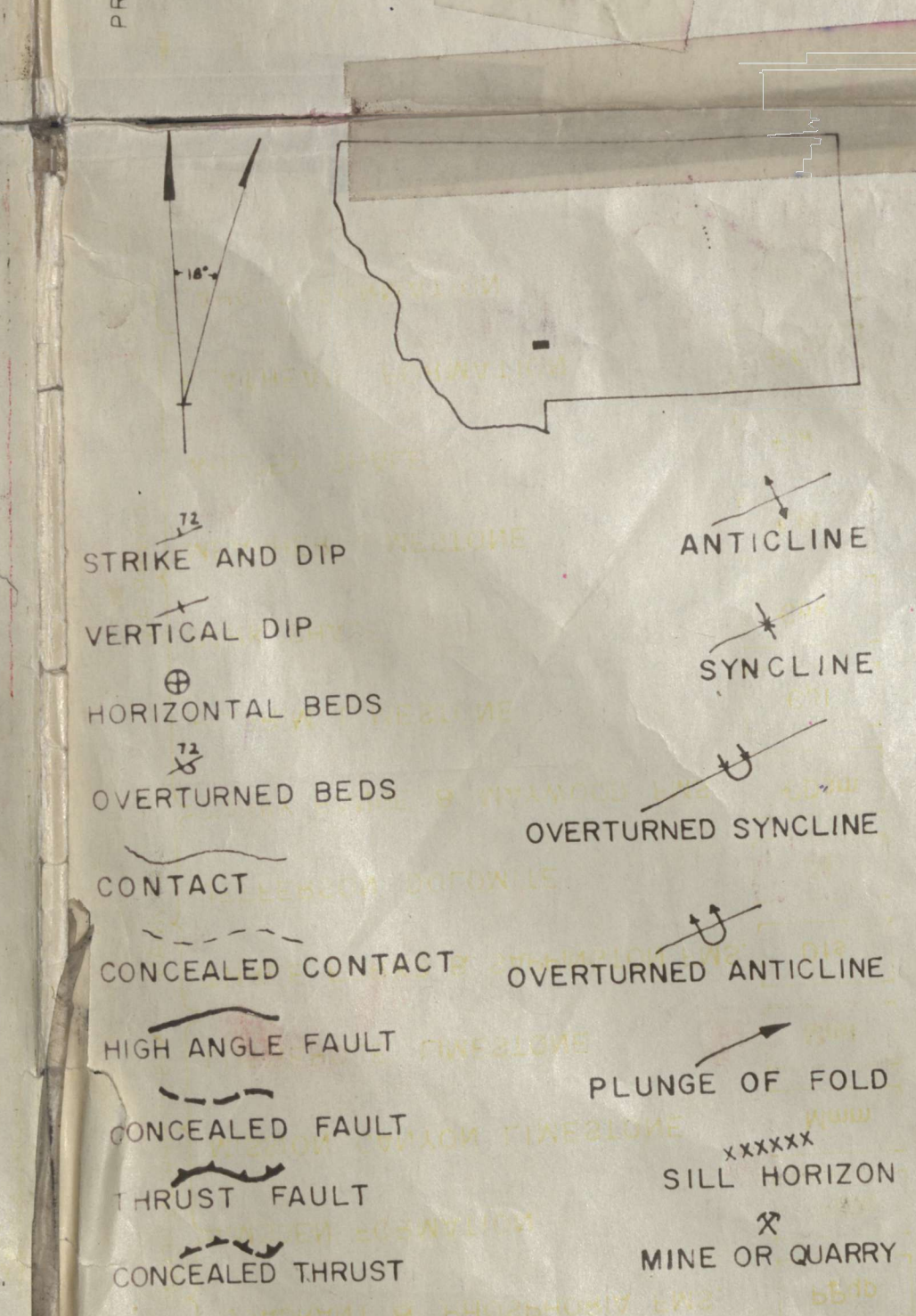


GEOLOGY OF THE SOUTHWESTERN HORSESHOE HILLS AREA, GALLATIN COUNTY, MONTANA

BY RONALD A. SPAHN, JR.

PRESENTED TO THE FACULTY OF THE
DEPARTMENT OF EARTH SCIENCES, IN
PARTIAL FULFILLMENT OF REQUIREMENTS
FOR THE MASTER OF SCIENCE DEGREE
AT MONTANA STATE UNIVERSITY, BOZEMAN
1967

QUATERNARY	RECENT ALLUVIUM	Qra
	OLDER ALLUVIUM	Qoa
	TRAVERTINE	Qt
	TUFFACEOUS BEDS	Tt
CEENOZOIC	CEENO GROUP	Kc
	KOOTENAI FORMATION	Kk
	MORRISON FORMATION	Jm
	ELLIS GROUP	Je
	QUADRANT & PHOSPHORIA FMS.	PPqp
	AMSDEN FORMATION	Pma
	MISSION CANYON LIMESTONE	Mmm
	LODGEPOLE LIMESTONE	Mml
	THREE FORKS & SAPPINGTON FMS.	Dts
	JEFFERSON DOLOMITE	Jf
	SNOWY RANGE & MAYWOOD FMS.	cDsm
	PILGRIM LIMESTONE	Epl
	PARK SHALE	Epk
	MEAGHER LIMESTONE	Em
	WOLSEY SHALE	Ew
	FLATHEAD FORMATION	Ef
	LAHOOD FORMATION	pCl



MONTANA STATE UNIVERSITY LIBRARIES



3 1762 10015533 0