Geology of a portion of the Norris quadrangle with emphasis on tertiary sediments Madison and Gallatin counties, Montana
by Sylvia Harrison Feichtinger

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Earth Sciences (Geology)
Montana State University
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Abstract:
The purpose of this study was to map the geology of an area composed of approximately the northern half of the Norris quadrangle and to describe the rock units and geologic history, emphasizing Tertiary sediments and the structural and depositional history of the southwest part of the Three Forks basin.

Exposures in the map area consist of Precambrian gneiss and amphibolite, scattered outcrops of Middle Cambrian strata, a variety of igneous bodies, and Cenozoic sediments.

Two major northwest trending faults, the Elk Creek and the Cherry Creek, extend into the map area. Evidence indicates three stages of movement on the Cherry Creek fault, reverse during Laramide time and normal during Oligocene and Recent. The Laramide and Recent movements were paralleled by those of the Elk Creek fault. Middle Cambrian strata were folded prior to reverse movement on the Cherry Creek fault and later deformed by younger Laramide faults. Metamorphic rocks were apparently folded during the Precambrian.

The Red Mountain rhyolite body, a probable vent, may have been emplaced after folding of Middle Cambrian rocks. Breccias on the southern end are possibly extrusive. A lithologic unit northwest of Red Mountain is interpreted to be composed largely of rhyolite debris eroded from Red Mountain. Extensive flows of andesite partially cover this unit. Dacite sills in the Wolsey Shale are probably part of an extensive sill zone of middle Cretaceous age.

During Paleocene and Eocene time, the southern margin of the Three Forks basin was north of the map area, as north-side-up reverse fault movements produced a topographic high in the northern part of the area. During part of the Oligocene the basin margin was south of the map area and the predominantly lacustrine sediments of the lower Dunbar Creek Formation were deposited. Normal movement on the Cherry Creek fault resulted in the alluvial and sheet flood deposits of the upper Dunbar Creek. A lacustrine limestone unit, possibly younger than Oligocene, is exposed near Norwegian Creek.

A high bench, probably cut by an ancestral Madison River during early Pleistocene time, is covered by a Belt quartzite gravel, possibly derived from conglomerates to the south such as those of the Paleocene Beaverhead Formation.
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Date July 31, 1970
GEOLOGY OF A PORTION OF THE NORRIS QUADRANGLE
WITH EMPHASIS ON TERTIARY SEDIMENTS
MADISON AND GALLATIN COUNTIES, MONTANA

by

Sylvia Harrison Feichtinger

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

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in

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Introduction</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous Work</td>
<td>2</td>
</tr>
<tr>
<td>Stratigraphy</td>
<td>5</td>
</tr>
<tr>
<td>Precambrian Metamorphic Rocks</td>
<td>5</td>
</tr>
<tr>
<td>Sedimentary Rocks</td>
<td>7</td>
</tr>
<tr>
<td>Paleozoic</td>
<td>7</td>
</tr>
<tr>
<td>Flathead Quartzite</td>
<td>7</td>
</tr>
<tr>
<td>Wolsey Shale</td>
<td>8</td>
</tr>
<tr>
<td>Meagher Limestone</td>
<td>9</td>
</tr>
<tr>
<td>Cenozoic</td>
<td>9</td>
</tr>
<tr>
<td>Tertiary</td>
<td>10</td>
</tr>
<tr>
<td>Red Mountain volcanic-sedimentary unit</td>
<td>11</td>
</tr>
<tr>
<td>Dunbar Creek Formation</td>
<td>14</td>
</tr>
<tr>
<td>Norwegian Creek carbonate unit</td>
<td>21</td>
</tr>
<tr>
<td>Quaternary</td>
<td>23</td>
</tr>
<tr>
<td>Old alluvium</td>
<td>23</td>
</tr>
<tr>
<td>Upper rounded gravel</td>
<td>23</td>
</tr>
<tr>
<td>Lower rounded gravel</td>
<td>24</td>
</tr>
<tr>
<td>Other old alluvium</td>
<td>25</td>
</tr>
<tr>
<td>Recent alluvium</td>
<td>25</td>
</tr>
<tr>
<td>Colluvium</td>
<td>25</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table 1. Composition of Andesites</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>33</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Index Map</td>
<td>4</td>
</tr>
<tr>
<td>2. Idealized Sequence of Movements of the Cherry Creek Fault</td>
<td>40</td>
</tr>
<tr>
<td>3. Major Structural Features</td>
<td>47</td>
</tr>
</tbody>
</table>
LIST OF PLATES

In Pocket

PLATE

<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Geologic Map</td>
</tr>
<tr>
<td>II</td>
<td>Correlations of Measured Sections</td>
</tr>
<tr>
<td>III</td>
<td>Generalized Structure Map, Southcentral Montana</td>
</tr>
</tbody>
</table>
ABSTRACT

The purpose of this study was to map the geology of an area composed of approximately the northern half of the Norris quadrangle and to describe the rock units and geologic history, emphasizing Tertiary sediments and the structural and depositional history of the southwest part of the Three Forks basin.

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GEOLOGY OF A PORTION OF THE NORRIS QUADRANGLE
WITH EMPHASIS ON TERTIARY SEDIMENTS
MADISON AND GALLATIN COUNTIES, MONTANA

INTRODUCTION

The region covered in this study is comprised of approximately the northern half of the 15-minute Norris quadrangle, Madison and Gallatin Counties, Montana. Specifically, the area covers part of the southwest portion of the Three Forks basin and is bounded on the north and west by the edges of the Norris quadrangle, on the east by the Madison River, and on the south by outcrops of the Precambrian metamorphic complex (see Index Map, Figure 1).

The purpose of the investigation was two-fold: first, to make a detailed study of the general geology of the area and second, to attempt to clarify the history of the southwest portion of the Cenozoic Three Forks basin, concurrently making any possible contributions to the rather meager knowledge of the Tertiary Bozeman Group.

There have been no previous detailed geologic investigations of this area and even the most recent workers have relied on Peale's seventy-five year old reconnaissance for general reference. Changes in stratigraphic conventions, and inaccuracies and omissions inevitable in a broad scale work such as Peale's, certainly warrant a closer study of the area.
The Norris quadrangle is the SE1/4 NW1/4 of the Three Forks sheet, the 1° quadrangle (45°-46°N and 111°-112°W), mapped by Peale (1896) from 1883 to 1889. Douglass (1899) briefly described the exposures on the west side of the Madison River in his study of the "Neocene lake beds". The 1933 reconnaissance of the Tobacco Root Mountains by Tansley and Schafer includes the western portion of the area, but geology is as grossly generalized as in Peale's work. Several cross-sections of the Three Forks Basin are included in Pardee's study of Cenozoic block faulting published in 1950. Alden (1953) briefly discusses some of the physiographic features along the Madison River in his paper on the physiography and glacial geology of western Montana. The southeast portion of the area, near Red Mountain, is included in Alsup and Andretta's (1960) general investigation of the Cenozoic history of the Norris-Elk Creek area and Red Mountain itself is one of a number of igneous bodies discussed in a masters thesis prepared by Kavanagh (1965). The Norris quadrangle is included in the 1965 gravity and magnetic geophysical investigations of Davis, Kinoshita, and Robinson.

The geology of the Three Forks quadrangle, just north of the Norris quadrangle, has been mapped in detail by Robinson and is the subject of an extensive professional paper published in 1963.
The Tansley and Schafer reconnaissance covers the area to the west.

G. B. Schneider (1970) has made an investigation of the geology east of the Madison River for his masters thesis at Montana State University. McThenia (1960) has studied Precambrian rocks south of the map area and Kavanagh (1965) and other workers have investigated igneous bodies which lie to the south.
Figure 1. Index Map
STRATIGRAPHY

PRECAMBRIAN METAMORPHIC ROCKS

A detailed description of Precambrian rocks was not within the scope of this paper, but the extensive exposures of the rocks could provide material for a number of studies.

Precambrian exposures in the map area consist of metamorphic pre-Belt rocks, dominantly gneiss and amphibolite, with minor layers of schist and quartzite. The gneiss is generally banded white and black or pink and black and is composed mainly of quartz, feldspar, and biotite. Varieties with fewer ferro-magnesian minerals and consequently less pronounced banding appear to become increasingly abundant in the southern part of the area. Amphibolite occurs in layers or pods and ranges from types having about 40 per cent amphibole to types which are almost totally amphibole. Garnet is common in the amphibolite and locally is an important constituent in granitic layers. Discordant and concordant pegmatites are found throughout the area. The largest of these is about 1/5 mile long; most are considerably smaller. They consist mainly of quartz and feldspar. The schists are composed mainly of biotite with minor amounts of quartz or garnet.

Metamorphic rocks in the Tobacco Root Mountains have been divided
into two series (Tansley, Schafer, and Hart, 1933), the Pony and
the Cherry Creek. The Pony consists dominantly of gneiss and amphi-
bolite with minor amounts of schist and quartzite (Reid, 1957).
Early workers regarded the Pony series as the older of the two series
and believed an unconformity separated them. However, Reid (1957)
has found that in the type area, Pony metamorphics overlie the Cherry
Creek. He discovered no evidence of an unconformity. As the rock
groups appear to have undergone the same metamorphic history, he
believes them to be broadly of the same age. No marble or sillima-
nite schist was found in the map area and according to McThenia
(1960), this suggests that the metamorphic rocks may be equivalent
to the Pony. However, the use of the term Pony this far from the
type area may be questionable, particularly as Reid's work suggests
that the traditional distinction between the two series could be
re-evaluated.
SEDIMENTARY ROCKS

PALEOZOIC

Paleozoic and Mesozoic strata are absent from the map area with the exception of a deformed section of Middle Cambrian rocks northwest of Red Mountain and scattered outcrops of Flathead Quartzite.

Flathead Quartzite

The Middle Cambrian Flathead Quartzite unconformably overlies the Precambrian metamorphic rocks in a number of localities in the map area, all in the vicinity of the Cherry Creek fault zone. Complete sections of the formation are present in the Red Mountain area where the thickness of the formation, 325 feet, is somewhat greater than normal. Lithology is similar to Flathead outcrops elsewhere, consisting mainly of red medium-grained quartzite and quartz sandstone, in places varying in color from pinkish-white, to yellow or black. The formation is dominantly thick-bedded, but is thin-bedded in zones of crossbedding. The rock locally contains conglomeratic beds, with quartz pebbles up to 1/2 inch in size. In the Red Mountain area, highly glauconitic beds are found near the base of the unit. The formation grades upward into the Wolsey Shale.
Wolsey Shale

The Wolsey Shale is well exposed northwest of Red Mountain, particularly in the SW1/4 sec. 28, T. 2 S., R. 1 E. Lithologically, the Wolsey is similar to outcrops of the formation elsewhere in the region, consisting dominantly of gray-green or locally purple, very thinly laminated fissile micaceous shale. The shale commonly weathers to a distinct light blue. Light brown micaceous siltstone and fine-grained sandstone make up a minor part of the unit. These are usually thin-bedded and may be interbedded with shale. They are generally strongly calcareous. The shales may be calcareous along fractures and bedding planes, but are otherwise not notably calcareous, particularly in the upper part of the unit. Worm burrows are common.

Two dacite sills intrude the Wolsey Shale in the Red Mountain syncline. In this locality, one occurs about 100 feet from the base and is approximately 25 feet thick; the other occurs near the top and is approximately 57 feet thick. These sills are discussed in detail in the section on igneous rocks. The thickness of the Wolsey is about 290 feet in the SW1/4 sec. 28, T. 2 S., R. 1 E., including the thickness of the two sills. The contact with the overlying Meagher Limestone is gradational.
Meagher Limestone

The Meagher Limestone is well exposed in the Red Mountain syncline and in a small faulted anticline to the northwest. The lower part of the formation is typical gray and yellow mottled limestone, the silty yellow partings vaguely outlining beds about 1/2 to 1 inch in thickness. The middle portion of the unit is massive crystalline brownish weathering limestone, locally dolomitic or oolitic. This changes upward into "blue and gold" mottled fine crystalline limestone, somewhat darker than the lower mottled portion and with the gold mottles generally less continuous than in the lower limestone. The top part of the exposure in the Red Mountain syncline is highly silicified and is locally stained or altered red.

Large outcrops and blocks of red- to yellow-brown "jasper" are common in the area. These seem to be silicified Meagher Limestone altered as a result of contact of the andesite and rhyolite with the upper part of the Meagher exposure. The jasper is also found along faults in the Meagher. Again, the jasperization may be related to siliceous solutions derived from the igneous rocks.

CENOZOIC

Cenozoic rocks are by far the dominant sedimentary rocks in the map area. These are divided in this paper into three Tertiary and
five Quaternary units. With the exception of work by Robinson (1963) and Schneider (1970), very little detailed petrographic work has been done on the Tertiary sediments of the area and consequently they received much of the attention in this study.

Tertiary

Robinson (1963) presents a comprehensive historical summary of work on the Tertiary sediments. Peale in 1896 described the Tertiary rocks of the region as the "Bozeman lake beds", a term avoided by Matthew (1899) and later workers, who believed a fluvial and eolian origin more likely. Robinson's studies (1963) showed that all three genetic types (eolian, lacustrine, and fluvial) are present. The term, Bozeman Group, was proposed by Robinson (1963) to include the Tertiary sedimentary rocks of the Three Forks basin. He subdivided the group into the Eocene Sphinx Conglomerate and Milligan Creek Formation, the middle or late Eocene to early Oligocene Climbing Arrow Formation, and the Oligocene Dunbar Creek Formation. The Dunbar Creek is the only one of Robinson's formations recognized in the map area. Besides the Dunbar Creek Formation, two other units of probable Tertiary age were mapped, referred to herein as the Red Mountain volcanic-sedimentary unit and the Norwegian Creek carbonate unit.
Red Mountain Volcanic-Sedimentary Unit

The Red Mountain volcanic-sedimentary unit, an informal name used herein, crops out in the N1/2 sec. 28 and W1/2 sec. 27, T. 2 S., R. 1 E. The unit is mapped separately from the Dunbar Creek because it is lithologically distinct and may well be older than the entire formation. It is not extensive enough to warrant formational status. The unit consists of flow-banded massive rhyolite, rhyolitic sedimentary breccias and sandstones, and possible mud flow deposits. These appear to be composed largely of material derived from Red Mountain. As rocks of these types are found in the conglomerates of the Dunbar Creek Formation and beneath the andesite body, they are clearly older than the upper part of the Dunbar Creek but younger than the rhyolite.

Massive rhyolite, some glassy and flow-banded, is similar to Red Mountain varieties and evidently underlies the epiclastic material. Its distribution is irregular and it appears to "blanket" older formations, possibly suggesting an extrusive origin. It is included within the Red Mountain unit in mapping.

The following sequence of rock types is found in the SE1/4 SW1/4 sec. 27. It is representative of the variation typical of the unit. Outcrops in a small gulch consist of white massive porous rock composed of biotite, angular quartz and rhyolite fragments in
a fine matrix. The rock suggests a possible mud-flow but is monolithologic and could conceivably have formed as a friction breccia within an intrusion. A prominent exposure to the north of these outcrops consists of well stratified breccias dipping steeply away from Red Mountain, possible mud-flow breccias, and conglomeratic sandstones. The base of the exposure is pisolitic, and commonly iron and manganese stained. A chaotic breccia above the well stratified layers resembles the breccias of the southern part of Red Mountain (see page 29) but contains a much higher proportion of matrix. It could be a mud-flow deposit or a flow breccia. This breccia is overlain by thin-bedded pink and yellow conglomeratic sandstone containing sub-angular to sub-rounded quartz and angular rhyolite fragments. A pink pisolitic layer occurs at the top of the outcrop.

The breccia found beneath the andesite flow in the NW1/4 sec. 28 contains a higher proportion of quartz than those described above, a dilution of the rhyolite debris which might be expected as distance from source increased.

It should be noted that sedimentary features can form in an intrusive breccia (Irvine, 1965), a fact which makes the mode of origin of the Red Mountain unit rocks even more uncertain. Only those with an appreciable quartz content (quartz phenocrysts form less than five per cent of the rhyolite) can be regarded as clearly epiclastic. A detailed petrographic investigation might clear up
some of the problems, and in the process, shed more light on the nature of the Red Mountain body.
The Dunbar Creek Formation was first described by Robinson (1963) and is the uppermost of his pre-Miocene subdivisions of the Bozeman Group. The formation crops out in the northeast and southeast portions of the Three Forks quadrangle and in the northeast portion of the Norris quadrangle. Exposures can be traced along the west bank of the Madison River from Robinson's designated type section south to the Cherry Creek fault. The formation is also fairly well exposed on the west side of the high bench, disappearing beneath colluvium in sec. 5, T. 2 S., R. 1 E. Isolated outcrops of sediments in sec. 19, T. 1 S., R. 1 E., and sec. 13, T. 1 S., R. 1 W., are probably also Dunbar Creek. The base of the formation is nowhere exposed in the map area and the stratigraphically highest rocks are covered by Quaternary gravel.

Robinson describes the formation as consisting of "white to grayish yellow thick bedded tuffaceous siltstone, partly lacustrine and partly eolian, intricately laced with fluvialite sandstone and conglomerate" (1963, page 77). He lists dark bentonitic clay and white limestone as rare components. Proportions of rock types in the formation are given as 80 per cent tuffaceous siltstone and sandstone, 15 per cent quartzose sandstone, sand and conglomerate, and 5 per cent limestone, clay and claystone (Robinson, 1963, page 78). The formation is better indurated than the Milligan Creek and
Climbing Arrow Formations. It has little limestone, whereas limestone is the dominant rock type of the Milligan Creek. Conglomerate and coarse sandstone are less important constituents than in the Climbing Arrow (Robinson, 1963, pages 77-78).

In the present study, a number of measured sections were made. These are presented in Appendix A. Correlations of the sections are shown in Plate II. The formation in the map area is exposed to a higher stratigraphic level than in the Three Forks quadrangle. As might be expected, several lithologic changes occur toward the southern margin of the Three Forks basin.

The stratigraphically lowest exposures of the formation in the map area occur in the northeast corner in the cliffs rising steeply from the west bank of the Madison River. Partial Stratigraphic Section IV of the Dunbar Creek was measured in this area, about three miles south of Robinson's designated type section. The upper part of the formation is largely covered, but outcrops consist dominantly of yellowish gray quartzose sandstone and conglomerate. The portion of the section measured in the NE1/4 sec. 24, T. 1 S., R. 1 E. forms striking white exposures, eroding locally to bad landlike topography. The rocks here consist mainly of white to light brown tuffaceous siltstone, massive to thinly laminated, and locally calcareous. Ash beds occur near the top of this portion. Yellowish gray coarse-grained conglomeratic sandstone containing dominantly
quartz and gneiss fragments is common in the lower part of these exposures.

The rocks stratigraphically below those described above, measured in the N1/2 sec. 19, T. 1 S., R. 1 E., form a sequence similar to portions of the strata on the east side of the Madison River. These consist of alternating white thinly laminated fissile tuffaceous silt shale, massive "dendritic" siltstone and limestone, and coarse-grained to conglomeratic sandstone. Pink weathering layers of medium-bedded tuffaceous limestone become common near the top of this portion. The lowest exposures of the formation, measured above the river in the NE1/4, NE1/4 sec. 19, T. 1 S., R. 2 E., are a rather monotonous sequence of massive to thick-bedded light yellowish gray micaceous tuffaceous siltstone and sandstone with interbeds of coarse-grained olive weathering quartzose micaceous sandstone. These exposures are similar to the lower half of Robinson's type section.

The lower strata become progressively less well exposed southward.

Partial Stratigraphic Sections I and II, measured north of Red Mountain and south of the Cherry Creek fault respectively, are representative of the upper half of the exposures of the Dunbar Creek in the map area. They are characterized by a dominance of coarse conglomerate and "mud conglomerate", a term used informally to describe the typical pebbly siltstone of the formation. The
highest exposures in the Red Mountain section, capped by the upper rounded gravel, consist of about 200 feet of gray calcareous conglomerate containing dominantly angular fragments of metamorphic rocks, particularly gneiss, up to 1 foot across, interbedded with mud conglomerate, a light brown calcareous tuffaceous siltstone with scattered rock fragments. Below the metamorphic conglomerates is a conspicuous andesite and rhyolite conglomerate which can be traced westward to an andesite breccia, and northward to the Elk Creek fault section. A pinkish brown massive cliff-forming siltstone occurs directly below the andesite conglomerate, forming a useful marker bed. The lower portion of the section consists of a light brown tuffaceous siltstone, finer conglomerates, and coarse sandstone, the finer rocks becoming dominant downward. The lowest exposures are white tuffaceous siltstone and silt shale with calcite cemented ash beds. This part of the section is correlated with the upper part of section IV (see Plate II).

The conglomerates become less coarse away from the Cherry Creek fault, and metamorphic rocks become more dominant in the upper conglomerates as distance from the rhyolite and andesite increases.

Ash beds in the strata are commonly cemented by calcite, which forms large sparite crystals up to 3 mm. across. The high porosity of the ash beds probably permits formation of the large crystals. Weathering of these layers sometimes produces a characteristic
rounded pellet-like structure. The age of the cementation is not known but certain structures associated with the beds are reminiscent of hot springs deposits. Such activity may be correlative with hot springs deposits east of the Madison River described by Schneider (1970).

The general lithology of the formation seems to indicate a transition from dominantly lacustrine to fluvialite deposition. Robinson (1963) has suggested that drainage was largely interior during the Dunbar Creek time and lake or bolson deposition was dominant. This interpretation is reasonable for the lower strata in the map area. The few coarse crossbedded sandstones present in the sequence possibly represent small stream deposits and might be a reflection of periodic drying suggested by Robinson. The thinly laminated and locally varved units are clearly lake deposits. The massive and thick-bedded tuffaceous siltstones may be eolian or lacustrine, depending on whether the ash has fallen into water or onto dry land. Robinson (1963) discussed this problem in some detail and concluded that periodic drying probably took place. He suggested that in Dunbar Creek time the climate may have been more arid than in the earlier Tertiary.

Clay fractions of two siltstone samples were examined by X-ray diffraction and were found to contain almost pure bentonite. This result agrees well with Robinson's data for several samples in
which the clay fraction was determined to be pure montmorillonite. Grim (1968, page 568) has suggested that it may be necessary for ash to fall in water in order to alter to bentonite, and that somewhat saline waters are particularly favorable for its formation. Thus lacustrine deposition of the tuffaceous siltstones may be indicated, but aridity is suggested. Flat mud pebble conglomerates in the sequence provide evidence for periodic drying. The dendritic calcareous siltstones and limestones may be fossil caliche horizons. The scarcity of fossil vertebrates in the formation in the map area also suggests aridity.

One interesting problem arises relative to the formation of montmorillonite from the ash in the sequence. Grim (1968) states that ash must have at least a moderate content of magnesium to alter to smectite (montmorillonite group). Robinson's (1963) analyses of tuffaceous siltstones, almost pure ash, indicate only about 1.3 percent MgO, well below the average for sedimentary and igneous rocks. A saline lake might be a logical outside source which supplied some of the magnesium required for smectite formation; however, much more detailed work would be necessary before any confidence could be placed in the idea.

The general transition upward to coarser clastic rocks in the Dunbar Creek may be due to an increasingly humid climate, or to tectonic control. Robinson (1963) believes that eastward tilting of
the Three Forks basin was taking place during the Oligocene, shifting deposition eastward. Such tilting could easily account for the increase in coarser clastic rocks. The normal movement on the Cherry Creek fault, however, apparently created a topographic high, resulting in the deposition of coarser clastic sediments over the finer units, and causing the transition from lacustrine to fluviatile and sheet flood deposition.

The age of the Dunbar Creek Formation has not been determined precisely. Robinson's (1963) fossil evidence dates part of the formation as Oligocene. In the present study only one vertebrate remain was found, a jaw fragment from an isolated outcrop just north of the map area in the SW1/4 NE1/4 sec. 13, T. 1 S., R. 1 W. This specimen was identified by G. E. Lewis (written communication, Jan. 1970) as *Leptomeryx evansi*, probably of Oligocene age, the species being particularly common in the lower Brule Formation of Nebraska. It is doubtful that the formation grades into Miocene age strata as there is good evidence for a late Oligocene-early Miocene hiatus in the area (Robinson, 1960 and Kuenzi, 1969) whereas there is no evidence of a major disconformity in the strata assigned to Dunbar Creek. Good radiometric dates might be obtainable from whole rock analyses of the ash in the formation as much of it is quite fresh and is rhyolitic in composition (Robinson, 1963).
Norwegian Creek Carbonate Unit

Exposures of Tertiary sediments along Norwegian Creek and in the vicinity of the Willow Creek Reservoir consist of striking white deposits of tuffaceous siltstones and limestones. The limestone represents about 120 feet of the 150 feet of exposures in the NW1/4 sec. 10, T. 2 S., R. 1 W. Measured sections of the formation are presented in Appendix B. The limestone, dominant in the upper part, is apparently related to a basin lake environment. It contains abundant ash and quartz. Algal colonies have been found in large blocks of the carbonate, unfortunately not in place. Massive tuffaceous siltstones dominate in the lower part of the unit. As no alluvial sands are present in the sequence it is doubtful that the siltstones represent flood plain deposits and the presence of scattered mud pellets precludes an eolian origin. They most likely are lake deposits. One poorly consolidated impure ash bed found in the section east of the reservoir is crossbedded and well-sorted and suggests eolian deposition.

The sequence may correlate with the lower sediments in the Dunbar Creek exposures of the map area or are perhaps a basin phase of the coarser upper sediments. However the freshness of the ash contained in the carbonates may be suggestive of a Miocene age. Several thin sections of these carbonates show that the ash is completely unaltered. Robinson (1960) has used the relative freshness of ash de-
posed in water to differentiate Miocene and younger deposits from older sediments. The younger ash is almost invariably unaltered while the older is usually partially devitrified. Other workers have apparently used this criterion with reasonable success (Robinson, personal communication, Dec. 1969). No fossils diagnostic of age have as yet been found in these sediments. Upper Dunbar Creek sediments are present on the margins of the present basin, surrounding the carbonate unit and at similar elevations to it, suggesting that these deposits may be erosional remnants from an earlier basin fill. However, the limestone could be expected to be a resistant unit, particularly under conditions of relative aridity. Thus, the converse could be true, the carbonate being a remnant of earlier Dunbar Creek deposition. Because of the uncertainty of the age of the sequence and because of the distinctive lithology, it is mapped as a separate unit, here called the Norwegian Creek carbonate unit.
Quaternary

Quaternary deposits are divided into five units, three of old alluvium, one colluvium and one recent alluvium.

Old Alluvium

Upper Rounded Gravel

An extensive gravel deposit caps the highest bench in the map area forming a continuous sheet covering approximately 18 square miles. The gravel is pebble to cobble size, some cobbles as great as 11 inches in diameter. The dominant rock type, approximately 80 per cent, is Belt quartzite and possibly some Flathead quartzite. Some metamorphic and igneous rocks are present. The gravel is well rounded. It commonly displays percussion marks, and occasionally, wind facets. At the head of the bench, north of the Cherry Creek fault, the gravel is about 80 feet thick. It thins northward and westward, and is generally no more than 10 feet thick on the west margin of the bench and less than 40 feet thick in the northeast corner of the area. The gravel does not occur north of the Jefferson River (Robinson, 1963).

The gravel is locally cemented by calcite, which frequently completely surrounds the rocks, a "cement-supported" rather than a "grain-supported" fabric. Robinson (1963) suggests that the calcite originated from channeled ground water or hot springs, but the
texture and distribution are perhaps more suggestive of "fossil" caliche horizons. The separation of the cobbles would not be unusual in a soil and is observed in present soils on the gravel surfaces. Soil blowing is presently a problem on the high benches (DeYoung and Smith, 1931) and it is not difficult to imagine that top soil has been stripped leaving only the thick caliche horizons. Detailed mapping of the lime-cemented zones would probably be instructive as to their origin.

The origin of the gravel itself poses a problem. The present gradient of the bench together with the thinning out of the gravel northward suggests an origin to the south where the nearest outcrops of Belt rocks are in the extreme southwest corner of the state. Eocene or Paleocene conglomerates to the southwest, such as the Beaverhead, contain abundant Belt quartzite cobbles and are the most probable source of the gravel (Schneider, 1970). The age of the gravel deposit has been discussed in detail by Robinson (1963) who concluded that an early Pleistocene age was reasonable.

Lower Rounded Gravel

A series of benches about 200 feet below the highest bench are well developed in the northeast portion of the map area along the west bank of the Madison River. These are covered by a gravel similar to the upper gravel but which contains a higher proportion of
metamorphic rocks, about 30 per cent. Quartzite from the upper bench has probably slumped down into the lower deposits. Lime cementation is more common than in the upper gravel.

Other Old Alluvium

Alluvium graded to levels above the present stream systems has been mapped as old alluvium. These deposits are generally coarser than the Recent alluvium and probably reflect a more humid climate. They are doubtless much younger than the rounded gravels and may be of Recent age.

Recent Alluvium

Recent alluvium, alluvium graded to present stream levels, is present along the Madison River and Norwegian and Elk Creeks and along minor spring-fed streams in the Red Mountain area. Except on the Madison River, the deposits are finer than the older alluvium of the area, reflecting the shift to the present rather arid climate.

Colluvium

Colluvium near the high bench consists mainly of gravel let down from the upper rounded gravel unit. The contact between the colluvium and the upper gravel was drawn on the projected thickness of the gravel where the prominent slope break marking the contact
of the gravel with the Tertiary is obscured. The contact with the lower rounded gravel was arbitrarily placed at the slope break at the head of the lower benches.

The colluvium mapped in the area east of the Willow Creek Reservoir consists dominantly of material derived from the Precambrian metamorphic rocks.
IGNEOUS ROCKS

Three major types of igneous rocks are present in the map area. These include dacite sills, the Red Mountain rhyolite, and extrusive flows found south of the Cherry Creek fault and near the Willow Creek Reservoir.

Dacite Sills

The sills are found in the Precambrian gneiss and amphibolite, and in the Cambrian Flathead and Wolsey formations. Sills in the Precambrian are composed of light brownish pink dense, tough, porphyritic dacite. Phenocrysts are plagioclase, commonly zoned and as large as 5 mm. in diameter. The groundmass is composed of plagioclase, minor orthoclase, and quartz which fills the interstices between the plagioclase laths. The sill in the center of sec. 6, T. 2 S., R. 1 E. has caused noticeable alteration of the garnetiferous amphibolite which it intrudes. This sill is 8-10 feet thick and is well exposed for a distance of about 1/2 mile. A similar but much smaller sill occurs in the Precambrian in the NE1/4, NE1/4 sec. 14, T. 2 S., R. 1 E.

Dacite sills are found in the Wolsey Shale and in the upper part of the Flathead quartzite. The sills are apparently fairly continuous and are found wherever Wolsey is exposed. Intrusions in
the Flathead may be related to shaly beds. The sills are deformed together with the Middle Cambrian beds and are of a pre-folding or intra-folding age (see page 59). Vitaliano believes that the sills may be part of a relatively continuous zone extending from the Squaw Creek area to the Gates of the Mountains area near Helena. He and his co-workers have obtained radiometric ages from similar sills of 103 to 106 m. y. (personal communication, May, 1970).

A hornblende andesite porphyry sill from the Squaw Creek area has been dated at 103.5 ± 6.8 m. y. (McMannis and Chadwick, 1964). These sills may or may not be related to those which intrude the Precambrian. They are generally brown and altered, with abundant plagioclase phenocrysts, somewhat smaller than in the other sills. The groundmass is extensively sericitized and may have undergone some secondary silicification.
Rhyolite

The igneous body at Red Mountain was studied in detail by Kavanagh (1965). He divided the body into three lithologic units, light pink to reddish flow-banded rhyolite, "monolithologic" breccia and "in-place" breccia. The variation in the lithologies noted by this author is greater than suggested by these divisions. The un-brecciated rhyolite ranges from dense white non-flow banded varieties to a light gray glassy type with well developed flow-banding. Pink rhyolite is commonly associated with locations of brush fires which may have contributed to the oxidation.

Concentric, inward-dipping attitudes of flow-banding suggested to Kavanagh that the body was a vent and that the breccias were friction autobreccias. The general attitude of flow-banding was confirmed by the present study and the author concurs with Kavanagh's interpretation of the body as a vent. Breccias exposed on the south end of the body, however, differ markedly from those to the north and may possibly represent in part extrusive breccias. These breccias were not mapped by Kavanagh. They contain the entire range of rhyolite types as well as local clasts of gneiss up to 2 feet across. Rude, near-horizontal "bedding" is developed near the contact. Some zones up to 4 feet thick are composed of coarse sand sized rhyolite fragments. These breccias lie directly on the Precambrian gneiss, unlike the rocks of the northeast and east
portions of the body, which are emplaced against Cambrian Flathead. The irregular southern contact may have been produced by breccias flowing out onto the surface. The features described above could be explained by a friction type breccia and layering, slump features, graded "bedding", and other sedimentary features are not uncommon in igneous intrusions (Irvine, 1965). Further work would be necessary before definite conclusions could be drawn.

Other breccias within the rhyolite mass do not include the range of rhyolite types found in the southern breccias and as they are not always found along the contact; probably represent local autobrecciation. The "in-place" breccias described by Kavanagh may be cataclastic breccias associated with the Cherry Creek fault. Scarp faces on the north side of Red Mountain suggest that the body has been offset by the fault but colluvium obscures the relationship. Disruption of the body could be related to any of the stages of movements on the fault (see page 38). The emplacement of the rhyolite could have been controlled by the fault, although there is presently little evidence to support this.

The age of the rhyolite is difficult to determine from the available evidence, although reliable radiometric dates could probably be obtained. The rhyolite is apparently older than the andesite (see page 35), however the base of the andesite exposures is presently 700 feet below the top of the Red Mountain intrusion.
This might imply an age difference between the bodies at least
great enough to provide time for a fair amount of erosion, unless
the rhyolite produced a substantial topographic bulge or indeed
was partially extrusive. In this context it is interesting to note
that clasts of rhyolite occur at the same stratigraphic level in
the Dunbar Creek conglomerates as clasts of andesite, but no lower,
suggesting near contemporaneity. Kavanagh (1965) tentatively
suggested the age of the rhyolite to be Eocene. An upper age
limit is provided by the andesite, which as yet is not precisely
dated. The body does not appear to be deformed by the Laramide
folding and is probably younger than that deformation.

Kavanagh (1965) describes the rhyolite as consisting of about
75 per cent microcrystalline groundmass and 25 per cent phenocrysts
of orthoclase, sanidine, quartz, and biotite.
Andesite and Basalt

Extrusive andesite is exposed over large areas northwest of Red Mountain in secs. 19, 20, 21, 27, 28, 29, T. 2 S., R. 1 E. The thickness of the body is estimated to be as much as 400 feet.

The andesite is variable in appearance. Light gray dense varieties are exposed at lower elevation in secs. 28 and 29. Locally these outcrops are white weathering and scoriaceous. Near the Cherry Creek fault the andesite is dark colored and highly vesicular. The rock exposed in sec. 20 is variable, but is commonly red and flow-banded or vesicular.

Thin sections made from several types show that the samples vary in mineralogy. The composition of several samples is shown in Table 1. In these specimens, plagioclase laths suitable for use in determining extinction angles were difficult to find, partly because of their small size. Generally, angles averaged about 20 degrees, indicating a slightly sodic composition (Michel-Lévy method). Andesite was therefore deemed a satisfactory classification for the rocks. It is conceivable that the whole rock chemical composition would not be as variable as the mineralogy, depending on the composition of the ground mass. Differences in the mineralogy and appearance of the body from one area to another, together with the non-uniform occurrence of the vesicular zones suggest that more than one flow may be present. The problem warrants closer
<table>
<thead>
<tr>
<th>Sample no.</th>
<th>%plagioclase</th>
<th>%hornblende</th>
<th>%pyroxene</th>
<th>%opaques</th>
<th>%groundmass</th>
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</thead>
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<tr>
<td>F70-1</td>
<td>50</td>
<td>*</td>
<td>10 ortho, 25*</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>red, flow-banded</td>
<td>50</td>
<td>*</td>
<td>10 ortho, minor clino</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>F70-3 vesicular</td>
<td>65</td>
<td>20</td>
<td>-</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>F70-4 oxidized, vesicular</td>
<td>55</td>
<td>5</td>
<td>3 ortho</td>
<td>-</td>
<td>37 (altered matrix)</td>
</tr>
<tr>
<td>RM4 vesicular</td>
<td>70</td>
<td>5</td>
<td>7 ortho</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>and clino</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* altered hornblende included in opaques

For sample locations, see Plate 1.
investigation than was possible in this study.

Two small remnants of a flow occur east of the Willow Creek reservoir in sec. 11, T. 2 S., R. 1 W. The general appearance of the flow is similar to vesicular portions of the andesite near Red Mountain, but thin sections reveal a rather different composition. The rock contains about 50 per cent plagioclase, 45 per cent opaques and altered hornblende, and 5 per cent augite. Phenocrysts of plagioclase, hornblende, and augite are present in minor proportions. The hornblende is similar to basaltic hornblende except that it lacks noticeable pleochroism, perhaps because it is extensively altered to hematite. Alteration bands around the hornblende are extremely common. As in the andesite samples, plagioclase suitable for compositional determinations was rather rare, but did have a fairly consistent extinction angle of about 30 degrees, that of labradorite (Michel-Lévy method). Because of the calcic composition of the plagioclase and the high proportion of ferromagnesian minerals, the flow should probably be classified as a basalt.

Correlation of the flow with the andesite near Red Mountain is therefore tenuous. Paleomagnetic studies of both bodies were made, but results were inconclusive. Measurements indicated scattered magnetic orientations, probably as a result of lightening or other secondary effects, or perhaps tilting of the flows.

The age of the andesite is not known with certainty. A rhyo-
lithic sedimentary breccia found beneath the flow in the W1/2, NW1/4 sec. 28, T. 2 S., R. 1 E., is assumed to be composed of material from Red Mountain, which would indicate that the andesite is younger than the rhyolite body. Since the andesite breccia in the NW1/4, NW1/4 sec. 27, T. 2 S., R. 1 E. grades into the upper conglomerates of the Dunbar Creek Formation, it is clearly older than the upper Dunbar Creek. Unfortunately, the age of the Dunbar Creek is known only imprecisely, being dated simply as Oligocene (Robinson, 1963, page 79). The occurrence of the andesite exclusively on the south side of the Cherry Creek fault suggests that the flow was controlled by a fault valley or topographic low created by the Laramide reverse movement on the fault. The distribution could also be explained by north-side-up faulting of the andesite and subsequent erosion from the northern block; however, far more erosion would thus be required to produce the subsequently beveled surface (see page 41 and Figure 2). It is possible that the fault acted as a conduit for the flow. The broad age range assignable to the andesite, possibly younger than Paleocene to early Eocene and older than part of the Oligocene is not inconsistent with andesite flows in the Gallatin Range which have been dated as Eocene (Chadwick, 1970). Mineralogic data are not diagnostic enough to substantiate correlation with these flows, nor, as previously noted, were paleomagnetic measurements of any value. Chemical analyses might shed light on possible
correlation. Good potassium-argon dates could probably be obtained from the Red Mountain rhyolite and the older age limit of the andesite thus made more precise, if the andesite itself proved to have too little datable material to yield reliable results.

The age of the "reservoir basalt" may have to remain a minor mystery. The flow appears to rest on Precambrian metamorphic rock, it probably would not yield reliable potassium-argon dates, and paleomagnetic orientations appear to have been altered.
STRUCTURE

Faults

The most prominent structural feature in the map area are two major northwest-trending faults, the Elk Creek and the Cherry Creek. These are consistent with the northwest structural grain of the region from north-central Yellowstone Park to the Tobacco Root Mountains (see Plate III). This structural belt contains a number of large northwest-trending faults, some as long as forty miles or more, with vertical displacements of up to 20,000 feet. The Cherry Creek fault zone can be traced at least thirty-five miles. Movement on these faults may be as old as Precambrian. Reid (1957) gives evidence of major Precambrian movements on the Mammoth and Bismark faults in the Tobacco Root Mountains and also postulates Precambrian strike-slip movement on the Pony fault.

Most of the displacement evident on the faults in the belt is Laramide in age. In general, the movement was reverse, with the north sides up. There is evidence for renewal of movement on the Cherry Creek fault during Oligocene time. This stage of movement was normal. Post-Pleistocene renewal of normal faulting occurred on both the Elk Creek and Cherry Creek faults in the map area. Apparently these post-Laramide movements are local phenomena as there is no evidence for similar displacements on other northwest
trending faults of the region or on the southeast extensions of the Elk Creek and Cherry Creek faults.

A third large fault is inferred to be present south of the Cherry Creek fault and northwest of Red Mountain. Its trend is roughly parallel to the Cherry Creek fault for about three miles. Several minor faults are associated with it. For convenience, the fault will be referred to as the Red Mountain fault.

The Cherry Creek Fault

The Cherry Creek fault is the southernmost of the two major faults in the map area. It is the northwest extension of the Squaw Creek fault, separated from it by the Gallatin range-front fault. The fault extends along the northeast side of Red Mountain, trending approximately N. 45 W. It apparently swings to an east-west direction at the north side of secs. 19 and 20, T. 2 S., R. 1 E. The fault becomes difficult to trace beyond the springs in the northwest quarter of section 19, but a fault which trends N. 65 W., near the southern end of the Willow Creek reservoir, is quite possibly an extension of the Cherry Creek fault zone.

Magnetic data of the area (Davis, and others, 1965) show a series of northwest-southeast trending lows from northwest of Harrison to the Willow Creek Reservoir and beyond, in line with the Cherry Creek fault. These lows are strongly suggestive of fault
zone continuation beneath Cenozoic sediments northwest of Harrison. The thick sedimentary accumulation along this trend indicated by gravity data of Davis, and others (1965) may be related to the fault zone.

Movement on the Squaw Creek fault is reverse, with Precambrian metamorphic rocks on the upthrown north side displaced against stratigraphic units from Cambrian up through the Colorado Group of Early Cretaceous age. The fault is covered by the Gallatin Range Tertiary volcanic sequence and by late early Eocene siltstones. Major movement was therefore between Early Cretaceous and early Eocene time. Minimum stratigraphic displacement is greater than 4,500 ft. and the dip-slip component of movement may be greater than 6,500 ft. (McMannis and Chadwick, 1964).

East of the Madison River, the stratigraphic relations on the Cherry Creek fault are obscured by alluvium, but according to Andretta and Alsup (1960), projection of the dips of the Middle Cambrian beds to the fault plane indicates that the Meagher Limestone is in contact with Precambrian gneiss in the subsurface. Consistent with movement on the Squaw Creek fault, Precambrian rocks are exposed on the north, upthrown side of the fault.

West of the Madison River, the fault has a more complex history, at least three stages of movement being indicated, one reverse and two normal (see Figure 2). Presumably, original movement was
Figure 2. Idealized sequence of movements of the Cherry Creek fault.

1. a) Laramide reverse fault movement. b) Extrusion of andesite. c) Beveling of surface. d) Deposition of lower Dunbar Creek sediments.
2. a) Oligocene normal fault movement. b) Erosion of upthrown block and beveling of surface. c) Early Pleistocene deposition of quartzite gravels.
3. Recent normal fault movement.
reverse, as on the southeast extension of the fault. Southeast of the Willow Creek Reservoir, Precambrian gneiss on the north is faulted against Cambrian Flathead Quartzite on the south. The preservation of a section of Middle Cambrian strata west of Red Mountain and south of the fault may well be a result of its being on the downthrown side of major fault movement.

Two igneous bodies lie along the Cherry Creek fault west of the Madison River. The rhyolite of Red Mountain has been mapped as a vent by Kavanagh (1965). An andesite flow can be traced from Red Mountain almost to the springs in NW1/4 sec. 19, T. 2 S., R. 1 E. The andesite body lies parallel to the fault and is exposed or preserved on the south side only. The rather problematical questions of the age of the bodies and their relationship to each other and to the fault are discussed in detail elsewhere in this paper. Both bodies are clearly older than part of the Oligocene Dunbar Creek Formation (see page 35).

Fine-grained and flat-lying lower Dunbar Creek sediments apparently were deposited subsequent to extrusion of the andesite. These fine sediments were most likely deposited on a surface of low relief which probably existed after some beveling of the uplifted block but prior to normal fault movement. No remnants of these sediments exist south of the fault and east of the Norwegian Creek drainage, but any sediments there could have been easily eroded
from the subsequently uplifted southern block.

A major reversal of the original fault movement apparently took place during some part of Dunbar Creek time, probably producing the present relationships of Precambrian rocks, andesite, and rhyolite faulted up against the lower Dunbar Creek sediments on the north.

This fault movement apparently controlled the deposition of the basinal sediments east of the Willow Creek reservoir throughout the remainder of Dunbar Creek time and possibly longer. This stage of fault movement is well documented by the abrupt coarsening in the section of Dunbar Creek sediments near the north side of the fault and by a thick sequence of very coarse andesite breccias and conglomerates which grade northeastward into finer, more typical Dunbar Creek deposits. The lowest of the coarse breccias and conglomerates contain vesicular andesite and rhyolite as well as tuffaceous siltstones similar to those in the lower part of the sequence. The percentage of clasts of metamorphic rocks increases upward, possibly reflecting erosion of the andesite and rhyolite down to the Precambrian gneiss. Directly opposite the fault (N1/2, NW1/4 sec. 27, T. 2 S., R. 1 E.) is a particularly thick sequence of andesite breccia and conglomerate which can be traced across the fault and directly to the flow.

The fault may have moved several times subsequently, but clear evidence exists for only one (normal) movement, which has noticeably
tilted the Pleistocene gravels on the large high bench which terminates at the fault. Scars which can be seen along the fault valley in secs. 20 and 21, T. 2 S., R. 1 E. and apparent drag folding of the sediments in the northwest quarter of section 27 are probably produced by this last movement. Andretta and Alsup (1960) recognized one stage of reversal of movement on the Cherry Creek fault west of the Madison River. They assumed that it took place after deposition of the Cenozoic sediments.

The magnitude of the various stages of movement along the fault zone is difficult to determine because of the reversals. The net displacement diminishes northwestward, either because of greater balance between opposite movements, or of smaller magnitude of initial displacement, or both. The net movement along the fault zone may be summarized as follows: Squaw Creek fault portion - net movement reverse, stratigraphic displacement greater than 4,500 ft.; fault portion from Gallatin Range front fault to Madison River - net movement reverse, stratigraphic displacement diminishing to about 500 ft.; fault portion from west of the Madison River to springs in section 19 - net movement normal, stratigraphic displacement less than 200 ft.; fault portion near southern end of reservoir - net movement reverse, stratigraphic displacement about 100 ft. The evidence is less clear northwest of the Willow Creek Reservoir,
but northwest to the vicinity of Harrison, Tertiary sediments are deposited south of the fault rather than to the north as on the east side of the reservoir. This may indicate that net reverse movement may persist. Northwest of Harrison gravity data indicate a thick accumulation of sediments north of the projected fault zone, implying that net normal movement may again dominate here.
The Elk Creek Fault

The northernmost of the two northwest-trending faults in the map area is the Elk Creek fault. The fault extends southeastward at least as far as the mouth of Gallatin Canyon; northwestward it may merge with the Cherry Creek fault zone. West of the Madison River the fault trends N 65° W. It forms well-defined scarp faces in the Precambrian gneiss, secs. 19 and 24, T. 2 S., R. 1 E. and produces a prominent offset of approximately 200 feet in the Tertiary strata and Pleistocene bench west of the Madison River.

As on the Cherry Creek fault, movement on the Elk Creek fault east of the Madison River is reverse. Mifflin (1963) mapped two parallel faults on the southeast extension of this zone with combined displacement of at least 1000 feet, north side up. He postulated a Laramide age for this movement.

West of the river, earlier fault movements are obscured by a later normal movement, which clearly occurred after the development of the Pleistocene bench. Tertiary sediments near the fault are not well enough exposed to permit speculation about Oligocene movement; however, it is apparent that the first and last noted stages of movement on the Cherry Creek fault are paralleled by movement on the Elk Creek fault.

An interesting relationship exists between the Madison Plateau east of the river, north of Elk Creek, and the large bench west of
the river. It seems probable that the Madison Plateau is an extension of the bench, as interpreted by Alden (1953). In spite of the eastward component of gradient of the benches, the Madison Plateau is 80-100 feet higher than the west bench at the same latitude. If the gradient of the plateau is projected southwestward, it coincides with the surface of the west bench, south of the Elk Creek fault. This relationship indicates either that the area on the north side of the Elk Creek fault west of the river was dropped down relative to the rest of the region, or that the areas to the east and south were uplifted relative to the north fault block. The former seems a simpler explanation.

The Red Mountain Fault and Associated Faults

The rather complex structural relationships in the Cambrian strata west and northwest of the Red Mountain are partially obscured by the andesite flow and by colluvium. The author's tentative structural interpretations are given below.

The Cambrian strata are folded into a southeast-plunging syncline, herein referred to as the Red Mountain syncline, and a series of en echelon folds (see Figure 3). The syncline is truncated on the east by a fault which places Cambrian Flathead and Precambrian gneiss against the Meagher Limestone. About 3/4 mile northwest, the Flathead and the Wolsey are offset about 50 feet by another
Figure 3
Major Structural Features

*PE* ..... Precambrian
*C* ..... Cenozoic
Unmarked...Laramide

*.... Flathead Quartzite

1 mile
small fault (see Figure 3). Both of these faults trend northeast-southwest and offset the strata, southeast side up. These could be tensional faults related to movement on the Red Mountain fault. In the SW1/4 sec. 28, T. 2 S., R. 1 E., the Meagher is faulted against the Flathead by the Red Mountain fault. This fault apparently continues eastward from the S1/2 sec. 28, T. 2 S., R. 1 E. to offset the Wolsey and disappear beneath the Red Mountain volcanic-sedimentary unit. The displacement on the fault can be interpreted as right lateral strike-slip, or more likely, normal, with possibly a minor left-lateral component. The fault is inferred to continue northwestward, where two springs occur in the Wolsey Shale. The fault disappears beneath the andesite in the NE1/4 sec. 29, T. 2 S., R. 1 E. The anticline in the N1/2 sec. 29 appears to be truncated on the north by the Red Mountain fault. No reversal of the dip was noted on the south side of the anticline in the Wolsey or Meagher and the south limb therefore is also interpreted to be faulted.

The en echelon folds in the Flathead in the N1/2 sec. 29, T. 2 S., R. 1 E. and the SE1/4 sec. 19, T. 2 S., R. 1 E. may be a result of a left lateral component of movement on the Red Mountain fault.

Northwestward, the fault becomes difficult to trace. It may continue with a northwest trend to intersect the springs in sec. 19, T. 2 S., R. 1 E., or may swing westward along the contact of the
Precambrian with the colluvium in secs. 24, 23, and 22, T. 2 S., R. 1 W. Springs and altered gneiss along this contact are suggestive of faulting. These would not necessarily be related to the Red Mountain fault, however. A fault distinct from the Red Mountain fault trending parallel to the valley south of Red Mountain may be postulated. This could intersect the spring in the SE1/4, SW1/4 sec. 19, T. 2 S., R. 1 E., and continue along the Precambrian contact. More detailed lithologic work in the Precambrian could yield more information about this possibility. Springs in the SE1/4 sec. 19 may be due to faulting or to the intersection of fractures in the andesite with the less permeable Flathead and gneiss.
Folding

**Precambrian crystalline rocks**

Numerous measurements of the attitude of foliation of the Precambrian gneiss and amphibolite were made throughout the map area. The attitudes are quite constant over broad areas. In the northern part of the map area, strikes are east-west to N. 45 W. Dips are generally steep, averaging about 65° N. Foliation in the southern part of the area has a similar strike, but dips are more gentle, about 20-30° N. East of Red Mountain and northward along the Madison River, the general strike of foliation is N. 45 W. to north-south. Dips are variable in magnitude, averaging about 30 degrees near Red Mountain and increasing northward to 80-90 degrees in the northernmost outcrops along the river. These attitudes suggest the existence of a large northeast-plunging anticline with an axis trending approximately north-northeast from the southern end of Red Mountain (see Figure 3). North-northeast-trending isoclinal folds in the Precambrian in the Madison canyon about eight miles south of Red Mountain were mapped by McThenia (1960).

Foliation of the Precambrian crystalline rocks beneath the syncline in the map area is not reflected in the deformation of the Paleozoic strata. According to McThenia (1960), the folding in the Madison Canyon is of Precambrian age. These facts, together
with the large discordance between the trends of the Laramide syncline and the anticline in the Precambrian rocks, indicate a probably Precambrian age for the formation of the anticline.

Paleozoic Strata

The Middle Cambrian formations exposed northwest of Red Mountain are folded into a southeast-plunging syncline with axis trending west-northwest, and a series of minor en echelon folds trending northwest. The syncline, truncated on the east by a fault, re-appears east of the Madison River. Peale (1896) mapped it as extending southeast to the Gallatin River. Beyond the river the synclinal trend continues, but the north limb is partly or entirely truncated by the Squaw Creek fault. Strata up through the Cretaceous Colorado Group are involved in the deformation. The age of the syncline is therefore post-Early Cretaceous and pre-faulting or "early" Laramide. The en echelon folds appear to be related to the Red Mountain fault which offsets the syncline (see Figure 3). They are therefore younger than the syncline, but are older than the andesite and probably represent a later Laramide deformation.

Tertiary

A number of folds are present in the Tertiary strata of the area. In many case the axes of deformation are impossible to determine
with any accuracy because of poor exposures, low angle dips and extensive crossbedding.

The largest Tertiary structure in the area is a broad synclinal basin which approximately underlies the large bench west of the Madison River. Position of the axis can only be inferred. Its probable trend is about N. 10 E., from the southwest corner of sec. 14, T. 1 S., R. 1 E. through the southwest corner of sec. 15, T. 2 S., R. 1 E. (see Figure 3). Dips on the east limb are generally 5 degrees or less. On the west limb they are as high as 15 degrees. The west limb is topographically somewhat higher than the east limb. Minor reversals in dip occur along the axis, forming a small roughly east-west-trending syncline-anticline pair near the large valley which dissects the northern part of the bench.

About two and a half miles west of the synclinal axis is an anticline (see Figure 3) with a similar north-south trend. It is truncated by the Cherry Creek fault on the south. It can be traced for only a few miles northward because of poor exposures. Near the fault, dips are as great as 35 degrees, probably as a result of some drag during fault movement. There may be a syncline about one mile west of this anticline, trending approximately north-south, but outcrops are very sparse in this part of the map area and good evidence is lacking.

Minor north-south trending folds are present in the Dunbar Creek
strata in the northeast corner of the map area.

East of the Willow Creek Reservoir (secs. 1, 2, 11, 12, T. 2 S., R. 1 W.) the Tertiary beds are relatively strongly deformed. A broad anticline (see Figure 3) is exposed in the southern part of section 2 and west half of section 12. The axis appears to trend about northeast. Dips are as steep as 30 degrees. North of the anticline is an east-west trending syncline which can be traced for less than a mile. The northern limb dips about 15 degrees to the south. West of the reservoir the strata are dominantly flat lying.

Tertiary structures mapped by Robinson (1963) in the Three Forks quadrangle have no preferred orientation and Robinson believes them to be primarily the result of readjustments of Laramide structures. The structures in the northern part of the Norris quadrangle seem to have either of two dominant orientations, the more important being approximately north-south and the other more or less east-west. As previously noted, exposures are rarely continuous enough to permit accurate determination of fold axis orientation and as a result these trends may be more apparent than real. There is evidence for recent movement on Laramide structures in the map area and a "re-adjustment" theory is perhaps more reasonable than postulating two compressional episodes to explain the fold development.
GEOMORPHOLOGY

Exhumed Topography

The resistance of the Precambrian rocks in the area has allowed preservation of a very early Tertiary topography throughout much of the region. Exhumation of the ancient topography is evident in the Elk Creek Valley and Norris Hills are (Montagne, 1960) and in the Three Forks quadrangle (Robinson, 1965). The northern half of the Norris quadrangle also exhibits this pattern. Isolated Tertiary deposits perched on the Precambrian bedrock are common throughout the area. Willow Creek has a well developed meander pattern as it passes through the Precambrian metamorphic rocks from the Willow Creek Reservoir to the Willow Creek Valley. These entrenched meanders are indicative of superposition of Willow Creek and provide evidence of a substantial accumulation of Tertiary sediments prior to erosion.

Benches

An interesting geomorphic feature of the area is the high bench west of the Madison River. This bench is apparently continuous with the Madison Plateau east of the river. The bench has been discussed in detail by Alden (1953), and Robinson (1963), and others. Alden believes the surface to be a terrace remnant formed by the
Pliocene or Pleistocene Madison River. He suggests that it may have been continuous northeastward from Table Mountain in the Tobacco Root Mountains and believes that the gravel cap may correspond to the Flaxville gravel of northeastern Montana. The Flaxville gravel, however, is purportedly of Miocene to Pliocene age (Robinson, 1963), and since an unconformity representing a substantial period of erosion exists between the Pliocene part of the Madison Valley Formation and the gravel cap of the Madison Plateau, Robinson (1963) concludes that the gravel is of Pleistocene age.

The gravels on the bench are well-rounded and moderately well-sorted and bear little resemblance to a glacial till. As previously noted, they are most likely derived from older conglomerates and not glacial deposits. Coarse angular gravels common on the surfaces in the western part of the map area may be derived from glacial deposits but were not investigated in detail. Gravel on the present Madison River has a size range similar to that of the older gravels but metamorphic rock types dominate. A detailed study of the distribution and imbrication of the upper gravel might reveal whether it was deposited in the thin sheet now present or in a system of meanders.

The lower bench level, upon which the lower rounded gravel is deposited, corresponds to the fourth bench level (second highest) described by Robinson (1963) and to the "second terrace" of Alden
(1953). It apparently represents a younger terrace than the upper level. Alden (1953) suggests that the benches between Norwegian Creek and Willow Creek may correspond to this level.

The Elk Creek fault has offset the high gravel veneered bench about 200 feet and produces scarp faces on the Precambrian rocks in sec. 19, T. 2 S., R. 2 E. and sec. 24, T. 2 S., R. 1 E. A small gravel patch (not mapped) south of the fault, SE1/4 sec. 23, T. 2 S., R. 1 E., may be colluvium or a remnant of the lower terrace level. If the latter is true then the fault has offset this lower level as well. No other remnants of the lower gravel exists south of the fault although the broad surface on the Precambrian, N1/2 sec. 25, T. 2 S., R. 1 E., may be related to the second level. While this study revealed no information as to the mechanism of initial superposition of the Madison River over the Norris Hills, rejuvenation of the river might have been caused by downwarping north of the Elk Creek fault. If the second terrace is faulted, however, rejuvenation must have been initiated prior to fault movement. Recent downwarping centered west of the river might explain why the river presently flows on the extreme west side of a valley cut through eastward dipping sediments.

Loess

Loess deposits are present in the northeast part of the map area
but are difficult to distinguish from soils derived from the lower Dunbar Creek Formation and were not mapped separately.

**Slump Features**

Slump features are prominent in two areas along the Madison River. A large slump block of the upper Dunbar Creek conglomerates is present just north of Red Mountain. The block is capped by the rounded gravel. The conglomerate beds and the upper surface of the block dip back toward the Dunbar Creek cliffs indicating that the block rotated as it slid.

An area roughly coincident with sec. 12, T. 2 S., R. 1 E. is covered by upper Dunbar Creek conglomerates which have apparently slid toward the river in a semi-coherent mass. Dips are steep and change abruptly over a distance of a few feet, probably reflecting "rumpling" of the beds. In the NE1/4, SE1/4 sec. 12, at the contact of the conglomerate with the Precambrian, the conglomerate dips 40 degrees toward the Precambrian rocks and the contact can hardly be regarded as depositional. This slump feature may have been initiated by undercutting of the strata by the Madison River.
GEOLOGIC HISTORY

The geologic record of the map area contains huge gaps and much of the history can only be inferred from the surrounding region.

The first important events for which there is evidence is the deposition of the sediments which were eventually metamorphosed to the Precambrian Pony series. Deformation of the metamorphic rocks apparently occurred during Precambrian time creating the general fold patterns observable today. Reid (1957) summarizes the pre-Belt geologic history of the Tobacco Root Mountains as consisting of a) a period of sedimentation; b) a period of high temperature metamorphism; c) a period during which basalt sills and dikes formed; d) a second period of high temperature metamorphism. Pegmatites formed during the latter parts of the second and fourth periods. Presumably the Precambrian history of the Norris quadrangle followed much the same pattern. Reid (1957) suggests that the large northwest trending faults of the Tobacco Roots were initiated during the formation of the Belt geosyncline and it is possible that the northwest trending Elk Creek and Cherry Creek fault zones were formed at this time. The Belt embayment was to the north of the map area and it is unlikely that Belt sediments were originally deposited in the area.

During the time of deposition of the Belt sediments and Early Cambrian time, the area included in this study was subjected to a
long period of subaerial erosion. In Middle Cambrian time the sea advanced from the west depositing the typical transgressive sequence of the Flathead, Wolsey and Meagher formations. No Paleozoic or Mesozoic sedimentary units younger than the Meagher are now present in the area but there is no evidence that the depositional history during these eras was notably different from that of the rest of southwest Montana.

During middle Cretaceous time dacite sills intruded the Wolsey Shale and upper Flathead Quartzite. Daugherty and Vitaliano (1969) have suggested that thickening of similar sills toward fold axes may indicate that deformation was contemporaneous with their emplacement.

Laramide deformation is expressed in the reverse movements along the Elk Creek and Cherry Creek faults and in the development of the Red Mountain syncline and Red Mountain fault. Much of the erosion of the Mesozoic and Paleozoic sediments on the upthrown northern blocks probably occurred at this time.

The Red Mountain rhyolite body was probably emplaced subsequent to formation of the Red Mountain syncline. Erosion of material from the body produced the sediments of the Red Mountain volcanic-sedimentary unit. Extrusion of the andesite took place some time after formation of this unit.

According to Robinson (1963), Laramide block faulting may
possibly have produced the framework of the Three Forks basin, but if major faults are present they are obscured by Cenozoic deposits. The Cherry Creek and Elk Creek faults are near the present southern margin of the basin, but as their Laramide movements were north-side-up, they can hardly have formed the southern edge of the early basin. The southern edge of the Three Forks basin during the early Tertiary, therefore, was probably north of the map area. Paleocene and Eocene rocks, with the possible exception of the Red Mountain unit, probably were not deposited in most of the area. Erosion and perhaps reversals of fault movement reduced the level of the topographic highs so that at least by Dunbar Creek time basinal deposition was occurring in the map area and southward. The Dunbar Creek basin was formed by regional eastward tilting and uplifts to the east (Robinson, 1963), and drainage, at least in the earlier part of its history, was internal. Major deposits were formed by airborne volcanic ash falling into intermittent lakes. Normal fault movement on the Cherry Creek fault shifted the basin margin northward again during the latter part of Dunbar Creek time. This movement, perhaps in conjunction with continued eastward tilting, resulted in the development of alluvial and sheet flood deposits in the map area, and through-flowing drainage was re-established.

External drainage and erosion continued through early Miocene time. During late Miocene and early Pliocene time basin deposition
occurred northeast of the map area. If Miocene and Pliocene deposition took place in the eastern part of the area, it was probably of a basin margin type. No gravels similar to the Pliocene type described by Schneider (1970) were found in the area. The present elevation of the Oligocene deposits is sufficient to account for the superposition of Willow Creek, if Recent downwarping north of the Elk Creek fault is taken into consideration, and thus thick accumulations of Miocene and Pliocene deposits need not be postulated. However, a basin similar to that presently rimmed by the resistant Precambrian rocks must have existed during the deposition of the Norwegian Creek carbonate unit. If this unit is indeed younger than the Dunbar Creek Formation then Oligocene strata in the western part of the area must have been substantially eroded. Thus, unless superposition of Willow Creek took place during Oligocene time, thick deposits of Miocene and Pliocene sediments must have been present in the area of the Willow Creek Reservoir.

The surface of the high bench was probably formed during early Pleistocene time by the ancestral Madison River and lower terraces were cut subsequently. Normal fault movement occurred on the Cherry Creek and Elk Creek faults sometime after the development of the high bench, and judging by the lack of dissection of scarp faces, during Recent time. The movement on the Elk Creek fault was apparently due to local downwarping north of the fault.
CONCLUSIONS

While a general investigation of this type seems to uncover as many problems as it solves, the study has established a number of geologic facts.

The Cherry Creek fault zone extends at least 8 miles northwestward beyond the Madison River and probably farther. There is evidence for at least three stages of movement on the fault, reverse during Laramide time and normal during Oligocene and Recent. The Laramide and Recent movements were duplicated by those of the Elk Creek fault. Recent normal movement on the Elk Creek fault was probably due to local downwarping north of the fault. Laramide deformation is also evidenced by the inter-related folding and faulting of Middle Cambrian strata northwest of Red Mountain.

The reverse north-side-up movements on the faults exerted an indirect control on the southern margin of the Three Forks basin during Paleocene and Eocene time. Dunbar Creek basinal sediments were deposited in the map area and Robinson's (1963) suggestion of intermittent drying is supported by the occurrence of flat mud pebble conglomerates and possible caliche zones. Oligocene normal fault movement controlled deposition, at least locally, during late Dunbar Creek time, and again the southern margin of the Three Forks basin was subjected to some tectonic control.

Dacite sills invade the Wolsey Shale and upper Flathead
Quartzite; these may well be part of an extensive sill zone of middle Cretaceous age. The Red Mountain rhyolite body, interpreted to be a vent, may have reached the surface, forming extrusive breccias. Major andesite flows are younger than the rhyolite. Both andesite and rhyolite are older than upper Dunbar Creek conglomerates.

Willow Creek could have been superimposed without substantial accumulation of Miocene and Pliocene sediments in the area. If the Norwegian Creek carbonate unit proves younger than the Dunbar Creek, however, such accumulation may be indicated.
APPENDIXES
APPENDIX A

Partial Stratigraphic Section I

This section was measured in the W1/2 sec. 26, T. 2 S., R. 1 E.

It represents approximately the upper half of the Dunbar Creek Formation exposed in the map area.

Quaternary Upper Rounded Gravel

32. Gravel, pebble and cobble size, up to 11" in diameter, well rounded, unconsolidated. About 70 per cent quartzite, of which about 5 per cent may be Cambrian Flathead, the rest Belt; 20 per cent metamorphic and 10 per cent igneous, both intrusive and extrusive................................................................. 50'

Oligocene Dunbar Creek Formation

31. Largely covered, but conglomerate subcrop up to slope break where gravel begins................................. 50'

30. Conglomerate; pebbles mainly gneiss or quartz fragments, with a minor proportion of dense, black igneous rocks, angular to sub-angular and generally less than 1" in size. Matrix is white, strongly calcareous. Resistant, forms ledges................................. 20'

29. Covered interval....................................................... 6'

28. Conglomerate, like 30 but coarser, clasts up to 3". Crossbedded................................................................. 15'

27. Covered interval....................................................... 30'

26. Conglomerate, like 30 but thin-bedded and cross-bedded................................................................. 8'

25. Largely covered, but outcrop is very light brown,
fine-grained, calcareous sandstone with some pebbles. Weathers rounded and appears massive except thin-bedded where weathering has "etched" out crossbeds...... 24

24. Conglomerate, like 30 but thin-bedded................. 6'

23. Conglomerate, extremely coarse, with metamorphic rock fragments up to 1' in diameter......................... 6'

22. Conglomerate, dominantly metamorphic fragments up to 6", angular. Grades to finer size upward................. 30'


20. Conglomerate; lowest of the dominantly metamorphic conglomerates. Generally thin-bedded and cross-bedded. Some rhyolite and andesite fragments are present. Metamorphic fragments may be up to 5" in size, but are generally finer. Matrix is white and strongly calcareous. Less coarse than the conglomerate directly below............................. 9'

19. Conglomerate; lowest of the coarse conglomerates in section. Very coarse angular vesicular andesite blocks up to 8" dominate, with abundant rhyolite present. Clasts of tuff, tuffaceous limestone, and rhyolite breccia also occur; an assemblage similar to the Red Mountain volcanic-sedimentary unit. Gneiss fragments are present, but infrequent. The matrix is strongly calcareous. Contact with siltstone below abrupt and channeled. Conglomerate forms prominent ledge above siltstone cliff............. 12'


17. Siltstone, like 18 but nonresistant and brownish......... 8'

16. Conglomerate, light gray to brown. Mainly fine, fragments generally less than 1/2", but a few "stringers" of pebbles up to 2". Most fragments fine grained intrusive or extrusive igneous rocks. Coarse crystalline quartz and plagioclase is present, most likely having a metamorphic source.
Fragments mainly sub-angular to sub-rounded. Matrix is strongly calcareous. Crossbedded..................... 15'

15. Siltstone, light brown, calcareous, tuffaceous. Mainly nonresistant, but becoming ledge forming upward. Contains small, discontinuous lenses of conglomerate........................................ 11'

14. Limestone, whitish brown, silty, somewhat tuffaceous. Abundant calcite stringers and void fillings. Resistant, ledge forming........................................ 2'

13. Conglomerate, gray, crossbedded. Like 16......................... 9'

12. Siltstone, light brown, calcareous, tuffaceous. Massive................................................................. 5'

11. Sandstone, coarse-grained, gray, calcareous. Resistant, crossbedded. Weathers dark gray................. 3'

10. Siltstone, light brown, calcareous, tuffaceous. Thick-bedded, crossbedded. Resistant, ledge forming... 9'

9. Conglomeratic sandstone, dark gray. Extremely friable and porous. Discontinuous; at this station forms lens about 8' long and 1' thick. Grains mainly quartz and black rock fragments, some gneiss. Very little matrix; this contains a large proportion of ash. Calcareous cement........................................ 1'

8. Siltstone, light brown, calcareous, tuffaceous. Somewhat resistant and indistinctly stratified......... 12'

7. Siltstone, light brown, calcareous, tuffaceous. Massive but indistinctly stratified. Nonresistant. Coarser and less calcareous than unit below.............. 13'


5. Covered interval............................................................. 14'

4. Limestone, light gray, tuffaceous. Shaly interbeds. Beds about 1 1/2" thick. Sparite crystal faces visible, locally exhibits poikilitic cementation....... 4'
3. Silt and clay shale, white, very tuffaceous. Thinly laminated, poorly indurated, porous, nonresistant. Not calcareous. ............................ 21'

2. Covered interval .......................................................... 7'

1. Siltstone, white, calcareous, extremely tuffaceous. Massive, resistant, ledge forming ..................... 2'

Base covered.

Total 437'
Partial Stratigraphic Section II

This section was measured in the SW1/4, SE1/4 sec. 14, T. 2 S., R. 1 E., just to the south of the Elk Creek fault. Like section I, it represents the upper part of the Dunbar Creek Formation.

Oligocene Dunbar Creek Formation

23. Conglomerate. Mainly metamorphic fragments up to 4" in diameter, some rhyolite and andesite, angular. Matrix white, strongly calcareous.......................... 13'

22. Sandstone, fine-grained, light brown, calcareous, tuffaceous. Scattered fragments of metamorphic rocks. Massive.......................... 16'

21. Covered interval................................. 4'

20. Conglomerate, like 18. Dominantly metamorphic fragments up to 4", some andesite, sub-angular to angular. Grades to finer size upward. Crossbedded, beds about 1" thick.......................... 22'

19. Conglomerate, like 17, but with scattered andesite clasts up to 4". Fine fraction mainly silt sized, coarse fraction mainly less than 1".......................... 13'


17. Conglomerate, like 16, but matrix coarser............... 7'

16. Conglomeratic sandstone, brown, calcareous. Scattered angular to sub-angular metamorphic fragments up to 1". Matrix medium sand size. Massive..................... 6'

15. Covered interval................................. 3'
14. Sandstone, fine-grained, light brown, calcareous. Scattered coarse grains of metamorphic rock fragments. Indistinctly crossbedded. 10'

13. Conglomerate, light brown, calcareous. Sub-angular metamorphic fragments less than 1/2" well scattered throughout fine sand to silt matrix. Massive. 5'

12. Covered interval. 3'

11. Sandstone, medium-grained, light brown, calcareous. Mainly quartz and metamorphic rock fragments. Massive. 8'

10. Siltstone, very light brown, white weathering, calcareous. Thin-bedded, crossbedded. 3'

9. Sandstone, coarse-grained to conglomeratic, light gray, calcareous. Mainly quartz and gneiss fragments. 4'

8. Siltstone and fine sandstone, light brown, calcareous. Quartz, plagioclase, and metamorphic rock fragments. Massive, round weathering, resistant. Forms cliff. 24'

7. Conglomerate. Very coarse, angular blocks of andesite and Red Mountain volcanic-sedimentary unit assemblage, scattered metamorphic rocks. Contact with units above and below gradational. 3'

6. Siltstone, like 4. 3'

5. Conglomerate, like 3. 1'

4. Siltstone, light brown. Scattered fragments of andesite. 2'

3. Conglomerate. Fragments of andesite, rhyolite, gneiss up to 3" but mainly less than 1". Contacts with units above and below gradational. Crossbedded. 1'

2. Siltstone and fine sandstone, light brown, calcareous, tuffaceous. Massive. To north of measured section this unit is whiter, finer grained and dominantly thin-bedded. 19'
1. Sandstone, coarse-grained to conglomeratic, light brown, strongly calcareous. Contains quartz, rock fragments, mud pellets. Appears massive, except where crossbedded. Grades upward into next unit. 5'

Base covered.

Total 181'
Partial Stratigraphic Section III

This section was measured in the W1/2 sec. 28, T. 1 S., R. 1 E. on the west side of the high bench. It most likely represents the interval from units 3 through 20 in Partial Stratigraphic Section I.

Quaternary Upper Rounded Gravel

8. Gravel, pebble and cobble size, heavily cemented by calcite. About 80 per cent is quartzite, the remaining 20 per cent metamorphic and igneous.............. 10'

Oligocene Dunbar Creek Formation

7. Covered interval................................................. 18'
6. Siltstone, light orange. Largely covered.................. 14'
5. Sandstone, fine to medium-grained, light orange, gray to black weathering, calcareous near top. Contains scattered gneiss pebbles. Locally weathers to concentric ridges about 2 mm. apart. Middle of unit is nonresistant but rest is ledge forming............. 25'
4. Covered interval.................................................. 5'
3. Siltstone and fine sandstone, light brown to light orange, slightly calcareous. Contains scattered angular gneiss fragments. Has gneiss lag gravel at top, pebbles mainly less than 1/2". Not as resistant as 5............................... 11'
2. Largely covered but light brown siltstone subcrop........ 74'
1. Ash beds, calcite cemented, gray to black weathering. Locally exhibits poikilitic cementation. Some concentric nodules. Locally medium-bedded............ 19'
Supplementary Section III

This section was measured about 1/3 mile south of Partial Stratigraphic Section III, in the SW1/4 sec. 28, T. 1 S., R. 1 E.

Quaternary Upper Rounded Gravel

6. Gravel, pebble and cobble size, heavily cemented by calcite. About 80 per cent is quartzite, the remaining 20 per cent metamorphic and igneous.......... 10'

Oligocene Dunbar Creek Formation

5. Covered interval............................................................... 20'

4. Conglomerate, yellowish gray, strongly calcareous. Mainly gneiss fragments less than 3/4", but some up to 2". Crossbedded......................................................... 4'

3. Siltstone and fine sandstone, light orange, gray to black weathering, calcareous near top. Contains abundant scattered gneiss pebbles. Locally weathers to concentric ridges about 2 mm. apart. Upper 3' conglomeratic, with gneiss fragments up to 2" and scattered black igneous fragments................................... 23'

2. Covered interval with some siltstone subcrop............. 103'

1. Ash beds, white to light gray, locally calcareous and may exhibit poikilitic cementation. Mainly thin-bedded, porous......................................................... 10'

Base covered.                                           Total 170'
Partial Stratigraphic Section IV

Units 1 through 5 of this section were measured in the NE1/4, NE1/4 sec. 19, T. 1 S., R. 2 E. Units 6 through 36 were measured in the N1/2 sec. 19, T. 1 S., R. 2 E. and the remaining units were measured in the NE1/4 sec. 24, T. 1 S., R. 1 E. This section represents the lowest exposures of the Dunbar Creek Formation in the map area. The top of the measured section is topographically about 40 feet below the elevation of the first sandstone outcrop in the SW1/4 sec. 13, T. 1 S., R. 1 E.

Oligocene Dunbar Creek Formation

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>57.</td>
<td>Siltstone, pebbly, grayish brown, calcareous. Medium-bedded, crossbedded.......................... 5'</td>
</tr>
<tr>
<td>56.</td>
<td>Siltstone, somewhat pebbly, slightly calcareous, light brown. Locally gray weathering. Medium-bedded... 16'</td>
</tr>
<tr>
<td>55.</td>
<td>Ash bed............................................................................. 6'</td>
</tr>
<tr>
<td>53.</td>
<td>Silt shale, very light brown to white, extremely tuffaceous. Not calcareous. Thinly laminated. Bottom half strongly convoluted............................. 5'</td>
</tr>
<tr>
<td>52.</td>
<td>Siltstone, light brown, tuffaceous. Appears massive but medium-bedded on weathered surfaces.................. 8'</td>
</tr>
<tr>
<td>51.</td>
<td>Ash beds, two, very thin, about 1&quot; apart............................... 2&quot;</td>
</tr>
<tr>
<td>50.</td>
<td>Siltstone, white. Massive.................................................. 1'</td>
</tr>
<tr>
<td>49.</td>
<td>Limestone, white. Thin-bedded, &quot;dendritic&quot;.......................... 2'</td>
</tr>
</tbody>
</table>
48. Sandstone, fine-grained, pebbly, very light brown, micaceous, tuffaceous. Thin- to medium-bedded.......................... 12'
47. Largely covered, some siltstone subcrop................. 40'
46. Silt shale or silty limestone, white, micaceous, strongly calcareous. Thinly laminated................. 1'
45. Covered interval.................................................. 5'
44. Siltstone and fine sandstone, light yellow, gray weathering, tuffaceous, strongly calcareous. Some quartz. Thick-bedded, resistant.............. 10'
42. Siltstone subcrop.................................................. 5'
41. Covered interval.................................................. 10'
40. Conglomeratic sandstone, yellowish gray, orange weathering, calcareous. Sub-rounded grains of quartz and metamorphic rock fragments................. 2'
39. Siltstone, very light brown, strongly calcareous. Massive................................................. 4'
38. Covered interval.................................................. 15'
37. Conglomeratic sandstone, yellowish gray, calcareous. Sub-rounded quartz and rock fragments, mainly metamorphic................................................. 5'

Offset to N1/2 sec. 19, T. 1 S., R. 2 E.
36. Covered interval.................................................. 40'
35. Limestone, gray. Medium-bedded. Resistant............ 10'
34. Siltstone, like 32.................................................. 6'
33. Ash bed............................................................... 3'
32. Siltstone, very light brown, "dendritic". Medium-bedded.................................. 6'
31. Limestone and interbedded silt and clay shale.................. 2'
30. Siltstone, "dendritic", like 32................................................... 1'
29. Limestone, orange, black weathering. Medium-bedded. Silty interbeds.................. 10'
28. Silt shale, light gray. "Dendritic". Thin-bedded...... 5'
27. Limestone, pinkish gray. Medium-bedded.................. 2'
26. Clay shale, like 20............................................................ 4'
25. Siltstone, very light brown, calcareous. "Dendritic". Medium-bedded.. 2'
24. Conglomeratic sandstone and conglomerate, orange to brown to olive. Mud pebbles common. Crossbedded. Slightly calcareous.......................... 2'
23. Silt and clay shale, light gray.......................... 1'
22. Covered interval.......................... 4'
21. Flat mud pebble conglomerate, orange, black weathering. 2'
20. Clay shale, white, tuffaceous. Orange interbeds. Some light pink limestone layers. Thinly laminated, fissile. Top 1' has alternating black and white varves........................................ 3'
19. Siltstone and fine sandy shale, light orange, calcareous. Very thin-bedded.................. 2'
18. Siltstone, light brown, calcareous, tuffaceous. Massive........................................ 1'
17. Sandstone, coarse-grained, channel. Like 16 but strongly calcareous and with Mn oxide stained layer at bottom.......................... 3'
16. Sandstone, coarse-grained, orange, olive green
to yellow. Contains quartz, mica and mud pebbles. Crossbedded, friable. Reddish brown stained layers at bottom......................................................... 2'

15. Siltstone, light gray, tuffaceous, micaceous. Some interbeds of medium-grained light olive micaceous sandstone. Slightly calcareous.................... 7'

14. Siltstone, white, orange weathering, tuffaceous, strongly calcareous, "dendritic".................. 1'

13. Siltstone and fine sandstone, like 11.................. 1'

12. Silt shale, white, tuffaceous, slightly calcareous, "dendritic". Thin-bedded.............................. 6'

11. Siltstone and fine sandstone, very light brown, tuffaceous, slightly calcareous. Contains tubes of calcite (travertine?) up to 2" in diameter. Scattered mud pellets. Massive.............................. 2'

10. Silt shale, very light brown, tuffaceous. Thinly laminated.......................................................... 1'


8. Siltstone, very light gray, strongly calcareous, tuffaceous, "dendritic". Massive, becoming shaly near top................................................................. 5'

7. Silt shale, white, tuffaceous, micaceous. Thinly laminated, but not fissile. Noncalcareous................ 4'

6. Covered interval................................................................. 40'

Offset to exposures on river

5. Siltstone and fine sandstone, like 3.................... 13'

4. Sandstone, medium-grained, olive, orange weathering, calcareous, micaceous, quartzose. Medium-bedded............ 3'

3. Siltstone and fine sandstone, very light yellowish
gray, tuffaceous, micaceous. Massive to thick-bedded. Locally gray weathering. Slightly calcareous........................................... 44'

2. Sandstone, coarse-grained, light yellow, brown weathering. Contains gray rock fragments, probably igneous............................................. 1'

1. Siltstone, white, light olive weathering, tuffaceous, micaceous, slightly calcareous. Thick-bedded............. 5'

Base at river.

Total  387'
APPENDIX B

Partial Stratigraphic Section V

This section was measured in the NW1/4, NW1/4 sec. 10, T. 2 S., R. 1 W., west of the south end of the Willow Creek Reservoir.

It is representative of the upper part of the Norwegian Creek carbonate unit.

Tertiary Norwegian Creek Carbonate Unit

14. Limestone, like 12, to top of bench......................... 4'
13. Covered interval......................................................... 10'
12. Limestone, white to light gray, sandy, tuffaceous.
   Medium-bedded.......................................................... 5'
11. Covered interval......................................................... 7'
10. Limestone, light brown, white weathering, tuffaceous.
   Contains quartz grains, calcite stringers. Bottom
   of unit partially covered........................................... 8'
  9. Limestone, light gray, tuffaceous, silty. Thin-
     bedded, ledge forming............................................. 8'
  8. Covered interval......................................................... 5'
  7. Limestone, gray, very tuffaceous, coarse crystalline.
     Medium- to thin-bedded, ledge forming. Weathers to
     small tubes locally. Vuggy........................................ 2'
  6. Limestone, like 4, largely covered......................... 15'
  5. Limestone, gray tuffaceous, coarse crystalline.
     One bed. Ledge forming.......................................... 1'
  4. Limestone, yellowish white, gray weathering, coarse
     crystalline. Medium- to thin-bedded......................... 8'
  3. Siltstone, like 1, but slightly darker and coarser..... 7'
2. Largely covered but with white quartzose limestone subcrop. ........................................... 49'

1. Siltstone, white to light brown, tuffaceous, somewhat calcareous. Contains scattered mud pebbles. Massive. Porous, not well indurated, but moderately resistant. .................................................. 5'

Base covered.

Total  134'
Partial Stratigraphic Section VI

This section was measured in the NE1/4, NE1/4 sec. 11, T. 2 S., R. 1 W., at the crest of the broad anticline. Most of the section is probably stratigraphically lower than Partial Stratigraphic Section V.

Tertiary Norwegian Creek Carbonate Unit

10. Sandstone, gray, limy. Grains are almost entirely sub-rounded quartz up to 2 mm. and "float" in cement.... 2'
9. Limestone, like 8, but medium-bedded.................. 4'
8. Limestone, white to light brown, tuffaceous, silty. Contains stringers of calcite. Thick-bedded.............. 5'
7. Silt shale, white, tuffaceous. Thinly laminated but not fissile. Grades into next unit....................... 5'
6. Covered interval.................................................. 11'
5. Siltstone, like 1.................................................... 2'
4. Covered interval.................................................... 19'
3. Siltstone, largely ash. Unconsolidated. Thin-bedded, crossbedded............................................... 1'
2. Covered interval, some siltstone subcrop.............. 18'
1. Siltstone, white to very light brown, tuffaceous, somewhat calcareous. Contains scattered mud pebbles. Massive. Porous, not well indurated, but moderately resistant........................................ 3'

Base covered.

Total 70'
REFERENCES CITED


Douglass, Earl, 1899, Neocene lake beds of western Montana and description of some new vertebrates from the Loup Fork: M.S. thesis, June 1899, Montana State University, Missoula, Mont.


* - denotes references used solely for compilation of Structure Map


NORRIS QUADRANGLE

CORRELATIONS OF MEASURED SECTIONS
DUNBAR CREEK FORMATION

PLATE II