Cenozoic volcanism and extensional tectonics of the Timber Hill map area southwestern Montana : disruption of a Neogene paleovalley

Yves Nicholas Garson

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CENOZOIC VOLCANISM AND EXTENSIONAL TECTONICS
OF THE
TIMBER HILL MAP AREA, SOUTHWESTERN MONTANA:
DISRUPTION OF A NEogene PALEOVALLEY

BY

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B.S. St. Lawrence University, 1989

Presented in partial fulfillment of the requirements
for the degree
Master of Science
University of Montana

1992

Approved by:

[Signature]
Chairman, Board of Examiners

[Signature]
Dean, Graduate School

Date
The upper Ruby Basin of southwestern Montana contains a paleovalley incised in Precambrian, Paleozoic and Paleogene rocks. A great thickness of rounded Belt Supergroup cobbles transported from the Pioneer and Beaverhead mountains, basalt, and ash from the Snake River Plain filled the paleovalley between 16 and 2 million years ago and is now known as the Sixmile Creek formation.

During the late Miocene, uplift and volcanism associated with the Heise volcanic field in the Snake River Plain, appears to have cut off the paleovalley's external drainage. This disruption resulted in a drainage reversal in which the Timber Hill basalt (6 Ma) followed the course of the paleovalley from the Snake River Plain to the Ruby Basin.

Following the Sixmile Creek formation deposition, the Huckleberry Ridge tuff surged across the present site of the Centennial Range, Centennial Valley, Gravelly Range and upper Ruby Valley, as far as the upper Ruby Basin. A small remnant of the Huckleberry Ridge tuff from the Timber Hill map area conformably overlies the Sixmile Creek formation.

Pliocene-Pleistocene block faulting apparently cut the paleovalley into several northwest trending tilted blocks. These blocks segmented and uplifted the south and southeast trending paleovalley.

Quaternary erosion has dissected numerous bedrock canyons of the upper Ruby Valley up to several hundred meters deep through the Huckleberry Ridge tuff. This suggests that uplift of the Ruby, Centennial and Madison Valleys occurred after emplacement of the Huckleberry Ridge tuff (known as Robb Creek tuff in this thesis).
ACKNOWLEDGEMENTS

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I would also like to thank the faculty and students of the University of Montana Geology Department (especially Monte Smith and Janet Riddell for their help), the Anderson family of Alder, Montana for the use of their cabin, my friends in Missoula and around the world, and my parents who, although they will never see this thesis, have been with me in spirit throughout my graduate school years.
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1. INTRODUCTION:

1.1 The Problem:

The Timber Hill map area is in southwestern Montana on the north flank of the Snake River Plain (see Fig. 1). Fritz and Sears (1989) discovered evidence of a structurally disrupted late Cenozoic paleovalley in the Ruby and Snowcrest mountain ranges of southwestern Montana, north of the Snake River Plain (see Fig. 3). This paleovalley is crucial in understanding the late Cenozoic tectonic evolution of the region because it contains a volcanic and sedimentary rock record that reflects mid-Miocene and Pliocene tectonic activity in the region (Sears, Fritz, and Alt, 1989; Fritz and Sears, 1989).

This thesis will attempt to establish the stratigraphy and structure of a segment of the paleovalley in the Timber Hill area of the Ruby mountains.

Fritz and Sears' (1989) preliminary work suggests that the headwaters of the paleovalley were in Belt Supergroup rocks of the Pioneer and Beaverhead mountains. The river flowed southeast in a broad valley, which crossed what is now the Highland, Ruby, Blacktail and Centennial mountains, and may have crossed the present-day Snake River Plain (see Fig. 2). Rhyolite and basalt, possibly derived from volcanoes along the Snake River Plain, as well as gravel, filled the valley during late Miocene and Pliocene time (Satterfield et al, 1989). Uplift along the Snake River
FIG. 1 LOCATION MAP OF SNAKE RIVER PLAIN-YELLOWSTONE PLATEAU VOLCANIC PROVINCE

EXPLANATION

- Location of the Snake River Plain-Yellowstone Plateau volcanic province in relation to certain other tectonic features, provinces, and linear zones of the western United States.

MODIFIED FROM BONNICHSEN ET AL, 1989
FIG. 2 SOUTHWEST MONTANA TERTIARY PALEOCHANNEL

MODIFIED FROM TOBACCO ROOT GEOLOGICAL SOCIETY GUIDEBOOK, 1989
FIGURE 3
UPPER RUBY PALEOVALLEY OF SW MONTANA

MODIFIED FROM TOBACCO ROOT GEOLOGICAL SOCIETY GUIDEBOOK, 1989
Plain appears to have cut off the valley's external drainage in late Miocene time. Pliocene–Pleistocene block faulting cut the paleovalley into several parts (Fritz and Sears, 1989; Sears, Fritz, and Alt, 1989). The disruption of the drainage appears to coincide with uplift and volcanic activity associated with the Heise volcanic field in the Snake River Plain (Bonnichsen et al, 1989). This volcanism was part of the late Cenozoic sequence of rhyolitic and basaltic volcanism that occurred along the Snake River plain. Many workers have attributed this volcanic activity to the southwestward migration of North America over the Yellowstone hot spot (Armstrong et al, 1975; Ruppel, 1982; Anders et al, 1989).

1.2 The Paleovalley

Sears et al (1989) suggested that the Neogene river valley, in the area of Timber Hill, was approximately 300 m deep and 100 km wide. This paleovalley incised the Paleozoic and Mesozoic rocks of the Pioneer Range to the west, Renova strata of the Upper Ruby basin and Paleozoic rocks of the Snowcrest Range to the east. Streams within the paleovalley transported distinctive pebbles and cobbles matching Proterozoic red quartzite units of the Belt Supergroup southeastward from the Pioneer and Beaverhead mountains (see Fig. 3).
Satterfield (1989) demonstrated that late Miocene rhyolite ash flooded the paleovalley in the vicinity of Timber Hill. Most of the ash was fluvially transported along with large pumice clasts and various cobbles. Evidence of basal surge deposits suggests that the ash originated from late Miocene calderas in the Snake River Plain (Bonnichsen et al., 1989; Satterfield, 1989).

This late Miocene ash overwhelmed the stream system and filled the paleovalley. Eventually, gravel from the northwest began to spread out over the paleovalley and alluvial fans prograded into the Pioneer and Snowcrest mountains. Sears, Fritz and Alt (1989) proposed that this dramatic change in sediment transport was the result of volcanic sediment choking the paleovalley's drainage in conjunction with the simultaneous uplift of the caldera region to the south (see Fig. 2).

According to Kreps et al. (1992), a 6 million year old basalt followed the course of the paleovalley from the Snake River Plain to the Ruby mountains area. This basalt may be outflow from the Blue Creek Caldera of the Heise volcanic field. The basalt appears to have migrated downstream toward the north from its source in the Snake River Plain. This indicates that the drainage direction reversed in the southern portion of the ancient river system.
1.3 Previous Investigations:

Most of the previous geologic investigations of the upper Ruby Valley have dealt with the Renova formation. This thesis is primarily concerned with the stratigraphy and structure of the Sixmile Creek formation.

In 1871, Ferdinand V. Hayden led a geological expedition through the upper Ruby Valley and described the rocks exposed in Sweetwater Canyon (Hayden, 1872). It was not until 1947, when John A. Dorr and Walter H. Wheeler began their paleontological investigation of the upper Ruby Valley, that geologic research resumed. Their description of the Tertiary Bozeman Group sedimentary deposits in the upper Ruby Valley was largely based on correlations with formations in adjacent basins. Dorr and Wheeler (1964) recognized two distinct, unconformably bounded units: 1) the Passamari formation - a basal formation of late Eocene to early Miocene, fine-grained lacustrine material with little to no volcanic ash; 2) the overlying "Madison Valley equivalent" - an upper unit of late Miocene age, based on a correlation of coarse material and characteristic fossils found in both the upper Ruby Valley and in the Madison Valley formation.

The Passamari formation became a member of the Renova formation and the Madison Valley equivalent became the Sixmile Creek formation. Monroe (1976) recognized three distinctly mappable members in the Sixmile Creek formation: a metamorphic fanglomerate member (Tsf), a feldspathic sandstone member (Tsm), and a quartzite pebble conglomerate member (Tsq). These members occur only in the upper Ruby Valley and were informally named.

The bedrock geology and structural history of the Ruby Range has been summarized by Karasevich et al (1981).

Sheedlo (1984) mapped a good deal of the structural geology of the Snowcrest Range in the northeastern section of the upper Ruby Valley.

Ripley (1987) examined Tertiary carbonates and their related sediments in the upper Ruby Valley in order to interpret the physical, chemical, biological, and climatic factors controlling carbonate deposition during the Tertiary in western Montana.

Satterfield (1989) described the Cretaceous/Tertiary stratigraphy of the Sweetwater Pass area of the upper Ruby Valley and obtained some K-Ar dates for the Renova formation.

Kreps and Fritz (1992) studied the Timber Hill basalt flow continuity and obtained a 6 Ma. date for this unit.
1.4 Scope of Thesis and Methods of Investigation:

The objective of this thesis is to establish the stratigraphy and structure of the Timber Hill area of the upper Ruby Valley. The Timber Hill area was chosen because: 1) it is well exposed, 2) it is at the intersection of the paleovalley and the important Cenozoic faults, 3) a working stratigraphy has recently been developed by Satterfield (1989), 4) it contains reliable radiometric dates (Fritz, written communication 1992), and 5) reliable fossil data has been collected (Monroe, 1976).

During the summer of 1991, 23 days were spent in the field collecting samples and mapping the Timber Hill area. Pre-Tertiary rocks were mapped only in a reconnaissance manner, while Tertiary strata and volcanic rocks, and their contacts with other rocks, were mapped in detail on 7 1/2 minute quadrangles. Four cross sections were constructed from the map data. One sample of tuff was K-Ar dated by J.M. Wampler of the Georgia Institute of Technology and chemically analyzed by W.J. Fritz of Georgia State University. One stratigraphic section was measured using a tape measure.

The Timber Hill area lies in Madison County, Montana, approximately 35 km southeast of Dillon (Fig. 4). It comprises approximately 256 square km and includes parts of the Red Canyon, Home Park Ranch, and Belmont Park Ranch quadrangles (see Fig. 5 and Plate 1). The upper Ruby Valley
FIG. 4 TIMBER HILL AREA LOCATION MAP

Modified from Sheedlo (1984)
FIGURE 5

SIXMILE CREEK FORMATION
OF THE UPPER RUBY VALLEY
is bordered by the Ruby Mountains to the north and west, the Blacktail Mountains to the south, and the Gravelly Range to the east (see Plate 1).

2. STRATIGRAPHY:

Rock units differentiated on the map (Plate 1) include the following: pre-Tertiary, Eocene? tuff, Tertiary rocks of the Bozeman Group including the Renova and Sixmile Creek formations, Timber Hill basalt, the newly discovered late Pliocene Robb Creek tuff and Quaternary alluvium.

2.1 Pre-Tertiary Rocks:

Exposures of Archean metamorphic rocks occur in outcrops adjacent to Sweetwater basin, Sweetwater Canyon and the upper Ruby Valley. Paleozoic units exist at the eastern boundary of the upper Ruby basin. The Archean rocks belong to the pre-Cherry Creek Group and primarily consist of coarse-grained banded gneiss with minor amounts of biotite schist and sillimanite-garnet gneiss (Heinrich, 1960). Peterson (1974) described the pre-Cherry Creek rocks as light-colored, banded biotite-hornblende-quartz-feldspar gneiss with minor amounts of magnetite, garnet and zircon. Heinrich (1960) found that most of the pre-Cherry Creek rocks were intruded by stringers of granitic material originating from the Dillon pluton to the northwest.
The pre-Cherry Creek rocks are generally foliated parallel to original bedding, strike northeast and dip 60 to 90 degrees to the northwest (Heinrich, 1960). Heinrich (1960) found that the pre-Cherry Creek rocks of the upper Ruby Valley show a great deal of structural variation ranging from large isoclinal folds to local ptygmatic folding.

Paleozoic rocks are exposed along the western, thrust-faulted edge of the Snowcrest Range. The Early Paleozoic units are generally poorly exposed and range in age from Middle Cambrian Flathead Sandstone to the Late Devonian Three Forks Shale (Sheedlo, 1984). The Upper Paleozoic units are somewhat better exposed and range in age from the Early Mississippian Madison Group to the Middle Pennsylvanian Quadrant formation (Sheedlo, 1984).

Mesozoic rocks generally rest conformably with the underlying Paleozoic rocks. The Triassic Dinwoody formation through the Early Cretaceous Kootenai formation are exposed along much of the eastern flank of the Snowcrest Range (Sheedlo, 1984).
2.2 Cretaceous or Tertiary? Silicified Tuff:

The silicified tuff unit is red, densely silicified, forms cliffs, and is approximately 150 m thick. It contains variegated liesegang banded material quarried as "picture rock". The tuff appears massive in the field, but Satterfield (1989) found several graded sequences within the unit. The tuff locally contains well-rounded Belt Supergroup cobbles.

The base of the tuff unit is gently dipping and forms a nearly planar contact with the Archean basement. It defines the west margin of the paleovalley. The upper contact is a "buried hill" covered by the Renova formation. The tuff pinches out to the south at Fries Place (see Plate 1) where the Renova formation is in depositional contact with Archean rocks. The western margin of the tuff is not well exposed due to mass wasting of the overlying units. It is absent in the Ruby Range to the west.

The silicified tuff resembles Eocene silicic tuffs that are related to the Challis volcanics of the region. For example, a very similar deposit in the Blacktail Range has an identical structural relationship: it is underlain by Archean rocks and overlain by the Renova formation (Tysdal, 1988) and lies at the edge of the same paleovalley. The age relations of the silicified tuff in the Timber Hill area are ambiguous. Satterfield (1989) determined a K-Ar age of late Cretaceous (67 Ma.), but noted that the sample contained
garnet and may have been contaminated by the underlying Archean rocks. The K-Ar dating problems have not been resolved yet. If the tuff is indeed Cretaceous, it would be related to the Elkhorn and Cold Springs Creek volcanics and the paleovalley would be at least Cretaceous in age.

2.3 Tertiary Stratigraphy - Bozeman Group:

Tertiary deposits of fluvial, lacustrine and eolian origin fill the upper Ruby Valley. These rocks comprise the Bozeman Group (Robinson, 1963) and have a total thickness of approximately 1.5 km (Monroe, 1976). The Bozeman Group unconformably overlies Archean through middle Eocene rocks and is unconformably overlain by Quaternary deposits.

The Bozeman Group in the upper Ruby Basin ranges in age from early Oligocene to Pliocene (Monroe, 1976) and is subdivided into two lithologically distinct rock units: the basal Renova and upper Sixmile Creek formations.

2.4 Renova Formation:

The Renova formation was named after the town of Renova, in the Jefferson basin, on the west side of the Jefferson River 6.4 km south of Whitehall, Montana (Kuenzi and Fields, 1971).
Using fossil data, Kuenzi and Fields (1971) assigned the Renova formation an age of early to middle Oligocene. Kuenzi and Fields (1971) used Oligocene fossils and the fine-grained nature of the Renova to correlate it with the Passamari formation of the upper Ruby River basin.

Monroe (1976) also recognized three members of the Renova formation and assigned them the following formal stratigraphic names: Climbing Arrow Member (Trc) (Robinson, 1963), Dunbar Creek Member (Trd) (Robinson, 1963), and Passamari Member (Trp) (Petkewich, 1972).

The Renova formation is mostly fine-grained strata interpreted to have been deposited in low energy flood plain and pond environments (Kuenzi and Fields, 1971). The Renova formation consists of deposits of 70% or more fine sand size or finer terrigenous rocks and less than 30% coarse-grained rocks (conglomerate is generally a minor component) that rest unconformably upon Archean rocks (Kuenzi and Fields, 1971). Kuenzi and Fields (1971) used fossil vertebrate data from the Jefferson basin to assign the Renova a late Eocene to early Miocene age. They found that the Renova correlates well with deposits mapped by Robinson (1963) in the Three Forks and Toston quadrangles as well as with the Passamari formation mapped by Dorr and Wheeler (1964) in the upper Ruby basin. Satterfield (1989) obtained a K-Ar date of 39± 3 Ma and Fritz et al (1992) obtained a date of 19.2 ± 0.4 Ma. from ash shards in the
Renova formation.

The Renova formation has been subdivided into three members: the Passamari, Climbing Arrow, and Dunbar Creek with a total thickness of 600-800 m. The Renova formation was not examined in detail in this study.

2.5 Sixmile Creek Formation:

2.5.1 General

The Sixmile Creek formation was named and defined by Robinson (1967) from Sixmile Creek near Toston, Montana. The Sixmile Creek formation overlies the Renova formation with an angular unconformity and is overlain with an angular unconformity by Quaternary deposits. The Sixmile Creek formation rests directly on Archean rocks west of Timber Hill. The base of the Sixmile Creek formation overlaps a middle Miocene fault and cuts approximately 600-800 m of tilted Renova formation in the Timber Hill area.

The Sixmile Creek formation was described in the Toston Quadrangle by Robinson (1967) as "coarse, light-colored, tuffaceous fanglomerate and shard-rich, sandstone subordinate, stream silt, pond limestone and airlaid rhyodacitic volcanic ash".
In the type area, the Sixmile Creek formation is more than 1200 m thick and ranges in age from early to late Miocene. The Sixmile Creek formation is typically coarse-grained, fine sand and coarser. Typical outcrops of the Sixmile Creek formation expose yellowish gray, white-buff gray, conglomeratic sandstone. Monroe (1976) described the overall section as consisting of approximately 49% sandstone (mostly conglomeratic), 28% conglomerate, 15% tuff, 5% siltstone, and 3% limestone.

2.5.2 Timber Hill Area

In the Timber Hill map area, the Sixmile Creek formation is about 600-700 m thick and consists of a basal feldspathic sandstone member, an ash rich unit, a metamorphic fanglomerate member, and a quartzite pebble conglomerate member (containing a thick gravel unit). It has a channel of Timber Hill basalt and is capped by the Robb Creek tuff.

The Sixmile Creek formation thins to essentially zero thickness on the east edge of the paleovalley.

One section of Sixmile Creek strata was measured in the Timber Hill map area (see Fig. 6). This section exposes approximately 200 m of strata and was measured in the Belmont Park Ranch quadrangle (see Plate 1). Portions of the base and middle section are covered with alluvium, hill wash and vegetation. The top of the section is conformable with the Robb Creek tuff.
FIGURE 6
ROBB CREEK MEASURED SECTION

ROBB CREEK Tuff 1.8 Ma,
Gravel 6 Ma.
Sandstone 12-13 Ma.
Siltstone 50 Ma.

50 Sandstone
100-39 Ma.
750 Gravel
150 Sandstone
Ash
200 Sandstone
Ash
250 Siltstone
250 Ash
300 Paleosol
Sandstone
350 Ash
400 Sandstone
Ash
450 Paleosol
Sandstone
Ash
500

1,8 Ma.

Upper Sixmile Creek Formation
Silicified Tuff
Precambrian Undifferentiated

Lower Sixmile Creek Formation
Renova Formation
From the base up, the Sixmile Creek formation consists of a 100 m thick feldspathic sandstone, a 45 m thick prominent ash unit, and a 145 m thick conglomerate unit.

In much of the Timber Hill study area the Sixmile Creek sediments are truncated by pediment surfaces and thinly veneered by Quaternary deposits.

**Feldspathic Sandstone**

The feldspathic sandstone member is dominated by medium to coarse grained feldspathic sandstone, conglomerate and tuff that grades laterally into the metamorphic fanglomerate and quartzite pebble conglomerate members. Compared to the metamorphic fanglomerate, the feldspathic sandstones contain little or no gravel, and the conglomerates are not as coarse.

The Sixmile Creek formation sandstones are generally grey, moderately well-rounded, medium-grained, friable, porous, and moderately well sorted, with a "salt and pepper" appearance. Most beds are 3-4.5 m thick. Many of the sandstones are tuffaceous and contain chert, quartz, feldspar, biotite, and volcanic rock fragments. Bedding in the sandstones is indistinct although, some units contain low angle cross beds. With increasing gravel content the sandstones grade into sandy conglomerates. Both the sandstones and the conglomerates are poorly to moderately well lithified. Calcite is the cementing agent. Channels
are the most common sedimentary structures.

The bottom of the Sixmile Creek formation unit consists of a mixture of silt, ash and paleosol.

The siltstone unit is light brown, fine-grained, and ranges from 3-15 m thick. It is generally covered.

**Volcanic Ash Unit**

A considerable amount of volcanic ash exists in the Sixmile Creek formation (Fig. 6 - Robb Creek Measured Section). The ash beds are white to buff, fine-grained, friable to moderately lithified, and range in thickness from 3-15 m. Some ash beds contain imbricated, stream worked basalt and quartzite clasts ranging from a few centimeters to 1/2 meter in length. These are generally elongate and rest parallel to bedding. The ash has a gnarly, pitted weathering appearance similar to that of the sandstone unit. Most of the ash beds are sandy or conglomeratic. Monroe (1976) described the composition of the ash as mostly fresh glass shards, pumice in variable amounts, and quartz-feldspar sand.

Sedimentary structures include horizontal laminations, bedding 2-10 cm thick and small-to-large festoon cross beds.

The Sixmile Creek ash is a very distinct unit. It has been dated to 12-13 Ma (Fritz et al, 1992) and was used as a marker unit for mapping purposes.
Gravel Unit

Gravel dominates the upper 145 m of the Sixmile Creek formation. The gravel generally weathers to a slope. Where it crops out, well-rounded pebbles, cobbles and boulders appear in a light brown-cream, sandy matrix.

Identified rock types include: 1) metamorphic rocks and vein quartz of Archean age 2) feldspathic pink quartzite (Belt Supergroup) 3) red and black chert, crinoidal limestone, dolomite, and red medium-grained, white fine-grained and brown fine-grained quartz arenite of Paleozoic age and 4) andesite, vesicular basalt, and amygdaloidal brown-red weathering basalt of Eocene age.

2.5.3 Distribution of Bedrock Sources for Gravel Unit

The top of the gravel is a constructional paleo-land surface that is capped by the Robb Creek tuff.

Most of the rock types in the gravel unit are derived from local sources such as the Archean, Paleozoic and Eocene rocks of the Ruby Range to the west. However, the primary sources of Belt clasts are the Pioneer and Beaverhead mountains to the north and northwest. Therefore, the Belt clasts represent exotic pebble types whose primary mechanism of transport was the southward flow of the upper Ruby Valley paleochannel.
2.6 Timber Hill Basalt:

This unit is reddish-grey to black vesicular basalt. Monroe (1976) described the basalt as containing plagioclase laths in a dark groundmass. Most phenocrysts are pyroxene and many are highly altered. Hornblende and magnetite are present in small amounts. The basalt is roughly 9-12 m thick and maintains a relatively constant thickness. Most of the flow has a blocky nature that locally displays columnar jointing. The basalt is generally aligned in a southeast-northeast direction and forms two detached mesas on either side of Sweetwater Canyon. Satterfield (1989) and Kreps et al (1992) traced the Timber Hill basalt southward along the paleovalley as a continuous "shoe-string", to Lima, Montana. The basalt is covered along Blacktail Deer Creek by gravel of the Sixmile Creek formation. The Timber Hill basalt rests on thick sections of the Renova and Sixmile Creek formations. On Timber Hill, the basalt overlies a thin veneer of gravel which rests on pre-Cambrian rocks. Southeast of the Timber Hill area, the Timber Hill basalt is about 1 km wide, and wedges out laterally into gravel. It is not seen in the Robb Creek section (Fig. 5), but cross-section analysis suggests that it occurs as an a lense about mid-way up through the gravel section. New K-Ar analyses suggest that the Timber Hill basalt is about 6 Ma. old (Kreps et al, 1992). It was previously thought to be approximately 4 Ma. old (Marvin et al, 1974).
2.7 Robb Creek Tuff (Huckleberry Ridge Tuff):

A tuff unit overlies the upper gravel unit of the Sixmile Creek formation on a small butte between Robb Creek and Ledford Creek (see Plate 1). In this thesis, this tuff unit is informally called the Robb Creek tuff.

The Robb Creek tuff lies conformably on the Sixmile Creek gravel and constrains the age of the widespread pediment surface (see Fig. 7). This tuff unit is approximately 3-4.5 m thick, platy, and contains 1-4 cm diameter fragments of sanidine, basalt, tuff, and pumice, all of which are matrix supported. These fragments are generally flattened parallel to the base of the tuff, are non-aligned, and are scattered several centimeters from each other. Weathered surfaces have a gnarly or pitted appearance. The Robb Creek tuff becomes more massive toward the base of the unit.

The Robb Creek tuff caps a small butte in section 32 of the Home Park Ranch quadrangle of the upper Ruby Valley. The Robb Creek tuff covers an area of less than 0.2 km² and occurs approximately 400 m above the modern valley floor. It yields a conventional K-Ar whole rock age of 1.8±0.1 Ma. (see Table 1). The Robb Creek tuff appears to be an outlier of the Huckleberry Ridge tuff. This date agrees with the 2.0 million year date reported by Obradovich and Christiansen (1983) for the Huckleberry Ridge tuff.
FIGURE 7

ROBB CREEK TUFF
Table 1

Radiometric Dates

<table>
<thead>
<tr>
<th>Sample #:</th>
<th>Rock Type</th>
<th>Method</th>
<th>Location</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>** NG-35</td>
<td>Rhyolite</td>
<td>K/Ar WR</td>
<td>Upper Ruby Valley</td>
<td>1.8±0.1</td>
</tr>
<tr>
<td>TH-147-90K</td>
<td>Basalt</td>
<td>K/Ar WR</td>
<td>Top of Timber Hill</td>
<td>5.9±0.2</td>
</tr>
<tr>
<td>SWP-89-111</td>
<td>Basalt</td>
<td>K/Ar WR</td>
<td>Timber Hill Flow North of</td>
<td>6.3±0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sweetwater Road</td>
<td></td>
</tr>
<tr>
<td>* DC-106C</td>
<td>Rhyolite</td>
<td>K/Ar WR</td>
<td>Tuff-Timber Hill</td>
<td>10.2</td>
</tr>
<tr>
<td>SWP-89-113</td>
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<td>K/Ar WR</td>
<td>Tuff-Southwest of Virginia Springs</td>
<td>19.2±0.4</td>
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<td>Timber Hill-Renova Formation</td>
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<td>Ruby Range-North of Sweetwater</td>
<td>42.0±4.2</td>
</tr>
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<td>Pass</td>
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<td>K/Ar WR</td>
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<td>123±2.0</td>
</tr>
</tbody>
</table>

* - Satterfield's (1989) dates
** - Dates Obtained from this thesis

These Radiometric dates were obtained under the Supervision of Dr. Marion Wampler of The Georgia Institute of Technology as part of an NSF Grant to Fritz, Sears & Wampler.

Data obtained from Fritz et al, 1992.
The Robb Creek tuff remnant is a high silica rhyolite nearly identical in major and trace element geochemistry to reported values of Huckleberry Ridge tuff from the Yellowstone Plateau volcanic field (Garson et al, 1992).

2.8 Quaternary Alluvium:

The Quaternary alluvium occupies flat-floored valleys. The alluvium is incised by the modern streams to a depth of a few meters. It is probably much thicker because no bedrock is exposed in the creek beds.

Erosional relief between the Robb Creek tuff and the Ruby River is approximately 400 m. This is Quaternary erosion.

2.9 Interpretation of Geologic Age of the Renova and Sixmile Creek Units (Monroe, 1976):

In this thesis, I will use the Cenozoic Land Mammal Ages of Woodburne (1987) (see Fig. 8). Regional geologic studies and comparisons of northern Rocky Mountain intermontane basin deposits have led to the recognition that many can be divided into two groups of strata separated by a regional unconformity (Kuenzi and Richard, 1969; Rasmussen, 1973; Fields et al, 1985). This unconformity is confined to Hemingfordian time during which most of the rock and fossil records of this age were eroded and lost from the geologic record (Woodburne, 1987).
Basal Renova Formation
(Climbing Arrow Member)

Conley Ranch Fauna

Fritz
39.2

Ruby Range Basalt
42.0 ± 4.2

Fritz
39.2

Hoffman
41.5 ± 0.9

Clast
46.1 ± 1.4

Eocene

Oligocene

Chadronian

Duchesnean

Uintan

Bridgerian

Wasatchian

Clarkforkian

Tiffanian

Torrejonian

Puercan

Modified from Woodburne, 1987
Monroe (1976) conducted a paleontological investigation of the upper Ruby River basin. He divided the vertebrate fossil assemblages of the upper Ruby River basin into 5 faunas, from the base up: the Conley Ranch fauna, the Belmont Park Ranch fauna, the Sweetwater Creek fauna, the Williams Ranch fauna, and the Ruby River fauna. All of the above mentioned faunas exist within the Timber Hill study area with the exception of the Williams Ranch fauna.

The Conley Ranch fauna specimens came from localities west of Sweetwater Creek in mudstones of the Climbing Arrow Member of the Renova formation. At fossil location MV 7209 (north of Timber Hill map area), the association of *Protoreodon pumilus* and *Oreonetes anceps* indicates an early Chadronian [early Oligocene] Land Mammal Age. Fritz's et al (1992) 39 Ma. K-Ar date (Chadronian/Duchesnean) (see Plate 1 - Geologic Map) is probably from the basal section of the Climbing Arrow Member. The K-Ar sample was collected close to the fault that juxtaposes the base of the Renova against the Archean basement.

The Belmont Park Ranch fauna was assigned to the Arikareean (late Oligocene-early Miocene: 20-29 Ma.) Land Mammal Age on the basis of *Oxydactylus longipes* found at location MV 7202 (north of field area). This fossil locality is high in the sediments of the Passamari Member of the Renova formation. MV 7252 is located just below the Renova-Sixmile Creek contact. This location yielded
numerous fossil specimens that were used to determine the
younger age limit of the Renova formation in the upper Ruby
define (see Plate 1) the Passamari Member.

The Sweetwater Creek fauna is confined to sediments of
the metamorphic fanglomerate and feldspathic sandstone
members of the Sixmile Creek formation (see Plate 1 and
refer to Monroe, 1976, Plate 1, Conley Ranch southwest,
Fossil Localities MV 6641, MV6642, MV7229, MV 6645 and MV
6639). The Sweetwater Creek fauna was assigned to the early
Barstovian [middle Miocene: 15-16 Ma.] Land Mammal Age based
upon the appearance of Merychippus seversus. Fritz's K/Ar
and Ar/Ar analyses suggest that the ash unit is probably 12-
13 Ma. old (Fritz et al, 1992).

The Ruby River fauna is located in the Conley Ranch
southwest (MV 7357), Ruby River (MV 7232) and Hale Draw (MV
7237 and MV 7238). It overlies the ash unit and appears to
be restricted to the Clarendonian (late Miocene: 8-12 Ma.)
Land Mammal Age. Megatylopus primaevus is present in the
Ruby River fauna and represents the earliest species of the
genus to appear in the fossil record.

The uppermost part of the Sixmile Creek formation is
unfossiliferous, but contains the 6 Ma. Timber Hill basalt
and is overlain by the 1.8 Ma Robb Creek tuff.
3. STRUCTURE

Monroe (1976) recognized 4 periods of tectonism in the upper Ruby River basin: 1) a period during which the basin was formed; 2) a period during the mid-Tertiary hiatus (middle Miocene); 3) a post-Sixmile Creek episode; and 4) a Pleistocene to Recent episode. This study is primarily concerned with periods 2-4.

Several high angle faults that trend northwest and northeast dissect the Timber Hill map area. Two of these faults have been reactivated. The cross-cutting relationship of the faults and the overlap of the Tertiary strata present a clear tectonic history of the Upper Ruby valley.

3.1 Northeast Trending Structures

3.1.1 Sweetwater Creek Syncline

The Sweetwater Creek syncline is a gently dipping structure that trends northeast-southwest. Its eastern limb is composed of the quartzite pebble conglomerate member (Tsq) of the Sixmile Creek formation, and dips from 4-10 degrees to the northwest. The western limb is composed of the quartzite pebble conglomerate (Tsq), feldspathic sandstone (Tsf) and metamorphic fanglomerate (Tsm) members of the Sixmile Creek formation in addition to the Passamari member (Trp) of the Renova formation. It is difficult to ascertain the direction of plunge.
3.1.2 East Ruby Fault

The East Ruby fault trends northeast-southwest and dips to the southeast. It juxtaposes Precambrian Undifferentiated against the Climbing Arrow member and the metamorphic fanglomerate member. These units appear to be offset approximately 250-650 m along the East Ruby fault. Relationships are not clear where the Precambrian Undifferentiated contacts the metamorphic fanglomerate member along the fault. It may be a depositional contact along the fault scarp, since the basal metamorphic fanglomerate member is made up of immature clasts derived from the Precambrian Undifferentiated.

If the metamorphic fanglomerate member was deposited along the fault scarp, the main period of faulting would be post-Renova (less than 19 Ma) and pre-metamorphic fanglomerate member (16 Ma).

The East Ruby fault is broken into four segments by the Stone Creek/Robb Creek, Timber Hill and South Timber Hill faults.

In the vicinity of Sweetwater Creek, a splay off the East Ruby fault places the metamorphic fanglomerate member in contact with the Climber Arrow member. This faulting also represents at least 650 m of offset.
A hot spring deposit (Tqhs) along the East Ruby fault in the vicinity of Sweetwater Road (Ripley, 1987) occurs at the base of the Sixmile Creek formation. This deposit has been named the Timber Hill carbonate (THRV) by Ripley (1987). She states that the carbonates do not form extensive interbeds within the Sixmile Creek formation but rather, occur in isolated areas. Monroe (1976) has interpreted these deposits as calcareous tufa and travertine derived from hot spring activity.

The Renova formation strikes into the East Ruby fault in several places. The Renova formation is tilted and is present only on the east side of the fault.

3.2 Northwest Trending Faults

3.2.1 Timber Hill Faults

The Timber Hill fault, a left lateral strike-slip fault, offsets the East Ruby fault by approximately 2 km. After deposition of the Timber Hill basalt, the Timber Hill fault was reactivated into a normal fault that offset the Timber Hill basalt by at least 250 m. The South Timber Hill fault is a high angle fault with less than 100 m of offset.
3.2.2 Stone Creek/Robb Creek Fault

The Stone Creek/Robb Creek fault trends northwest-southeast. From the southeast to the center of the Timber Hill map area, the Robb Creek fault juxtaposes various sandstone, ash, siltstone, gravel and conglomerate units of the quartzite pebble conglomerate member. In this section of the map area, the Robb Creek fault is a high angle fault that is down-dropped to the southwest.

In the vicinity of the Sweetwater triangulation mark, the East Ruby - Stone Creek/Robb Creek fault is a left lateral strike-slip fault that is offset by at least 5.5 km. The Stone Creek/Robb Creek fault was later reactivated into a high angle normal fault. This normal fault offsets the Climbing Arrow member (Trc) of the Renova formation approximately 650 m against the metamorphic fanglomerate member and offsets Precambrian Undifferentiated approximately 650 m against the metamorphic fanglomerate member.

In the northwest section of the Timber Hill map area, the Stone Creek fault juxtaposes the metamorphic fanglomerate member against the Climbing Arrow member and Precambrian Undifferentiated against the metamorphic fanglomerate member, representing at least 650 m of offset. In this part of the map area, the Stone Creek/Robb Creek fault "scissors" or changes its sense of movement. The Stone Creek fault is still a high angle fault but it is now
down-dropped to the east.

In the vicinity of the Robb Creek tuff, the Robb Creek fault was reactivated a second time. The original faulting occurred before deposition of the Sixmile Creek formation. The Renova formation is not present on the upthrown block. Sometime after the Robb Creek tuff (Huckleberry Ridge tuff) was deposited (1.8 Ma), the fault was reactivated, with a reversed sense of throw.

3.3 Homocline

The Timber Hill map area contains a large homocline with a constant dip of Sixmile Creek formation toward the north-northeast that is tilted toward the Greenhorn Range fault (see Fig. 9).

3.4 HISTORY OF FAULTING

The oldest fault in the Timber Hill map area appears to be the northeast trending East Ruby fault. It formed at the boundary between Renova and Sixmile Creek deposition (between 16 and 19 Ma). A younger, northwest trending set of faults is superimposed upon the East Ruby fault. These faults include: Timber Hill, South Timber Hill, and Stone Creek/Robb Creek faults. The original motion along these faults was left-lateral strike slip. This movement apparently occurred before deposition of the Sixmile Creek formation since, the metamorphic fanglomerate appears to be
FIG. 9 GREENHORN RANGE FAULT LOCATION MAP

Modified from Sheedlo, 1984
related to the fault scarp. However, as demonstrated by approximately 180 m of offset of the Timber Hill basalt along the Timber Hill fault, these faults have been reactivated since Timber Hill basalt eruption approximately 6 Ma ago. The motion along these faults has changed from strike slip to high angle normal dip-slip. It is difficult to determine if the reactivated fault post-dates the Robb Creek tuff since only a small remnant of Robb Creek tuff is evident in the Timber Hill map area.

4. SNAKE RIVER PLAIN/YELLOWSTONE PLATEAU VOLCANIC FIELDS:

Rhyolitic and basaltic volcanism has occurred intermittently in the Snake River Plain and the Yellowstone Plateau volcanic field for the past 17 Ma. Volcanic activity began as flood basalt in the southeast, then changed to resurgent caldera eruptions about 12-13 Ma ago, with the Bruneau-Jarbridge volcano (Bonnichsen, 1982). By 6.5 Ma ago, caldera activity had migrated to the Heise volcanic field just south of the paleovalley (Fig. 10). The Timber Hill basalt appears to have erupted from the Blue Creek Caldera of the Heise volcanic field approximately 6 Ma ago and flowed north down the paleovalley, where it mingled with gravel from the Snowcrest and Gravelly ranges.
FIG. 10 HEISE VOLCANIC FIELD

MODIFIED FROM CHRISTIANSEN AND BLANK, 1972
About 1.8 Ma ago, the Huckleberry Ridge tuff erupted from the Yellowstone Plateau and surged onto the top of the Sixmile Creek formation in the Timber Hill map area (See Fig. 11). After that, the Timber Hill and Stone Creek/Robb Creek faults were reactivated as normal faults.
FIG. 11. REGIONAL LOCATION MAP FOR THE YELLOWSTONE PLATEAU VOLCANIC FIELD

Regional location map for the Yellowstone Plateau volcanic field, showing configurations of calderas formed during three cycles and reconstructed distributions of the caldera-forming ash flow sheets. Big Bend Ridge (BBR) segment of the 2.0 Ma caldera associated with the Huckleberry Ridge Tuff, Henrys Fork (HF) caldera associated with the 1.3 Ma Mesa Falls Tuff, Yellowstone caldera formed during eruption of the 0.6 Ma Lava Creek Tuff. Northeastern margin of the first-cycle caldera was engulfed by the youngest caldera, and dashed limits of the Huckleberry Ridge and Mesa Falls Tuffs are wholly covered by younger rocks. GC, Grand Canyon of the Yellowstone River; M, Mammoth; MV, Madison Valley; N, Norris Geyser Basin; OF, Old Faithful; YL, Yellowstone Lake.

MODIFIED FROM HILDRETH ET AL., 1984
5. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

5.1 CONCLUSION:

The upper Ruby basin contains a paleovalley inscribed in Precambrian and Paleozoic rocks and Renova formation mudstones. Normal faulting along the East Ruby fault may have localized the drainage in a half-graben between the Ruby and Snowcrest ranges. The headwaters of this paleovalley may have originally been in Belt Supergroup rocks derived from the Pioneer and Beaverhead mountains.

During late Miocene and Pliocene time, the paleovalley filled with rhyolitic ash and basalt, probably derived from volcanoes along the Snake River Plain, as well as sand, silt and gravel. This rhyolitic ash flooded the paleovalley beginning approximately 12-13 Ma, when the Bruneau-Jarbridge volcano erupted. Most of the ash was fluvially transported along with large pumice clasts, Belt quartzite gravel and volcaniclastic sediment.

Uplift along the Snake River Plain during the late Miocene appears to have cut off the valley's external drainage. The disruption and reversal of the drainage appears to coincide with uplift and volcanic activity associated with the Heise volcanic field in the Snake River Plain. A 6 Ma basalt followed the course of the paleovalley from the Snake River Plain to the Ruby mountains. This basalt may have come from the Blue Creek Caldera of the

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Heise volcanic field. The basaltic lava flowed northeast across a low area on the Sixmile Creek surface. Following Sixmile Creek deposition, the Huckleberry Ridge tuff surged across the present site of the Centennial Range, Centennial Valley, Gravelly Range and upper Ruby Valley, as far as the upper Ruby Basin.

The Huckleberry Ridge tuff remnant mapped in the upper Ruby Valley is approximately 110 km northwest of the rim of the Huckleberry Ridge Caldera (see Fig. 11). The Huckleberry Ridge tuff has been previously mapped as far as 100 km from the caldera.

Pliocene-Pleistocene block faulting cut the paleovalley into several segments. Following the drainage reversal, the crust broke into several tilted blocks, generally trending northwest, on the uplifted flank of the Heise volcanic field. These blocks segmented and uplifted the south and southeast trending paleovalley. The uplifted blocks are less resistant than the adjacent pre-Cenozoic bedrock and form gently rolling hills of gravel and basalt.

The upper Ruby Basin Huckleberry Ridge tuff remnant conformably overlies a thick sequence of gravel from the Sixmile Creek formation. The surface across which it flowed is now deeply eroded, faulted, and tilted.

The Huckleberry Ridge tuff provides an important datum for Quaternary deformation and erosion in southwest Montana. Quaternary erosion has dissected numerous bedrock canyons up
to several hundred meters deep through the Huckleberry Ridge tuff surface in the Ruby, Snowcrest and Gravelly Ranges. A structure contour map created by Sears (1992, pers. comm.) of the base of the Huckleberry Ridge tuff suggests that it may be offset by thousands of meters along the Madison, Centennial and Blacktail range-front faults.
5.2 RECOMMENDATIONS FOR FUTURE WORK

I feel that there is still a considerable amount of work to be done in the upper Ruby Valley. From my undergraduate work in Cathodoluminescence (CL), I think that it would be worthwhile to compare quartz under CL from ash units in the upper Ruby Valley with ash units from the postulated source regions along the Snake River Plain. The wavelength, or color, of emitted light from quartz is indicative of its temperature of crystallization, duration of cooling, and/or its history of deformation. Therefore, the quartz obtained from these ash units could be used as a guide for provenance studies. If the ash contained within the Sixmile Creek formation is derived from sources along the Snake River Plain, then one should observe similar CL patterns. This technique could also be applied to a comparison between the Robb Creek tuff and the Huckleberry Ridge tuff in the Yellowstone area.

Another area that warrants further research is a more detailed geochemical comparison of the Robb Creek tuff to the Huckleberry Ridge tuff. This thesis only presents preliminary data.

One could conduct a geochemical comparison of the ash units in the upper Ruby Valley to the Bruneau-Jarbridge volcanic field as part of a regional provenance study. One could also undertake a geochemical comparison of the Robb Creek tuff to the rhyolitic ash flow tuffs reported by
Hadley (1969) in his Geologic Map of the Varney Quadrangle. Sears feels that these may be the same unit since the Varney Quadrangle is adjacent to the Home Park Ranch Quadrangle where the Robb Creek tuff was mapped in this thesis.
6. REFERENCES


U.S.G.S. Geologic Map of Montana, compiled by
in cooperation with the Montana Bureau of Mines

Woodburne, M. O., 1987, Cenozoic Mammals of North America:
Geochronology and Biostratigraphy, Univ. of Cal. Press,
336 p.