1996

Stratigraphic context of Miocene tephras in the Upper Ruby River basin and vicinity southwest Montana

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STRATAGRAPHIC CONTEXT OF MIOCENE TEPHRAS IN THE UPPER RUBY RIVER BASIN AND VICINITY, SOUTHWEST MONTANA

by

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B.S. Idaho State University, 1992
presented in partial fulfillment of the requirements
for the degree of
Master of Science, University of Montana
1996

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Stratigraphic Context of Miocene Tephra in the Upper Ruby River Basin and Vicinity, Southwest Montana (57 pp.)

Director: James W. Sears

The Ruby River Basin is a NE-trending graben located 40-km east of Dillon in southwest Montana, and is bounded by the Ruby Range to the west, and Greenhorn and Snowcrest ranges to the east. The basin contains more than 1-km of siliciclastic, carbonate, and volcanic rocks of the Renova and Sixmile Creek formations, deposited in fluvial and lacustrine environments. The Renova Formation is downfaulted into the graben, while the Sixmile Creek Formation is accumulated in fluvial and alluvial systems within the graben. The graben was cross-cut by NW-trending faults associated with the Yellowstone hotspot, after deposition of the Sixmile Creek Formation. Latest Cenozoic erosion has exposed excellent sections of the structurally disrupted graben-fill.

The Sixmile Creek Formation contains Miocene tephras apparently derived from vents on the Snake River Plain to the south. They provide both a stratigraphic and structural datum. The tephras were fluvially deposited in broad channels along the graben axis. As many as five separate tephra beds crop out in continuous stratigraphic sections exposed at several localities along the graben. The thickest is up to 30 m thick, and has been traced along the graben axis for 40-km. The tephras are interlayered with stream-transported gravel beds containing distinctive clasts. Tephra beds also occur in the Sixmile Creek Formation on the west side of the Ruby Range, but appear to be part of separate depositional system, possibly in a different graben basin. Provenance studies along with detailed mapping, radiometric dating, vertebrate fossil data and geochemical analysis provide evidence of a complex geologic history associated with the passage of the Yellowstone hotspot.
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CHAPTER 1
INTRODUCTION

1.1 Statement of the Problem

The Ruby River Basin is an asymmetric northeast-trending graben 40 km east of Dillon, Montana, located north of the Snake River Plain (Fig. 1 and 2). The graben terminates at range-front normal faults that occur along the margins of the bounding mountain ranges that separate late Cenozoic sediments from Precambrian and Paleozoic bedrock (Ripley, 1987). Fritz and Sears (1989) and Sears et al (1989) discovered evidence of a structurally raised late Cenozoic river valley in the block-faulted Ruby Range in southwestern Montana. The paleovalley is located on the north flank of the Yellowstone hot spot track (Fig. 3). Previous work by Fritz and Sears (1989, 1993), and Garson (1992) suggest that doming of the Yellowstone hot spot structurally raised the surrounding mountain ranges and cut off the southeast flow of a major river system that linked northwest Montana and southwest Montana, and resulted in widespread regional drainage reversals (Fig. 4).

1.2 Scope and Purpose

The Ruby River Basin, lower Beaverhead Valley, and Ruby Range provide an excellent opportunity to study the late Cenozoic tectonic activity for the following reasons: (1) well exposed volcanic and sedimentary rocks provide a record of mid-Miocene and Pliocene deposition and tectonic activity in the region; and (2) the Ruby Range is a linear structure that provides insight into the sense and amount of offset among several tilted mountain ranges in the region. Although previous work provides a framework for the stratigraphy and structural geology of the Ruby River Basin, Beaverhead Valley, and Ruby Range, it is the purpose of this thesis to bracket the timing of tectonic events using clast provenance, fossil data, and radiometric age dates of intercalated tephras in Tertiary sediments.

The primary objectives of this thesis are to: (1) develop complete measured stratigraphic sections of late Cenozoic sediments and volcanic deposits; (2) provide an up-to-date description of the structure of the Ruby River Basin, lower Beaverhead Valley, and Ruby Range; (3) determine the provenance of sedimentary clasts; (4) bracket the timing of structural events and the depositional history with radiometric age dates from intercalated tephras and fossil evidence; and (5) interpret the structural and depositional history of the region.

1.3 Methods of Study

During the summer of 1993, stratigraphic sections of the Miocene-Pliocene Sixmile Creek formation were measured with both a jacob staff and a tape measure. Clast composition was determined for each member, and tephra samples were collected at each measured section. The surface geology of the upper and lower Ruby River Basin, and
lower Beaverhead Valley areas were field mapped at the 1:24,000 scale. A 1:100,000 scale map was compiled from the field maps and Garson (1992) (Plate 1), five cross sections and a fence diagram were constructed from the map data (Plates 2 and 3). Plates 1-3 were also constructed with AutoCAD R.12 for windows software and are located in the back pocket (Appendix 1). Tephra samples were collected, geochemically analyzed and fission-track dated by P. Shane (1995) at the University of Toronto.

1.4 Previous work

In 1871 Ferdinand V. Hayden headed a party through the Ruby River Basin and described the hot spring deposits in the northern end of the area, the volcanic deposits along Sweetwater Creek and Tertiary deposits at the junction of Sweetwater Creek with the Ruby River (Hayden, 1872). The Tertiary deposits of the Ruby River Basin were later described by Douglass (1899). These and other intermontane Tertiary deposits of western Montana were referred to as "Bozeman Lake Beds" (Peale, 1896), or simply as the "Lake Beds" (Blackwelder, 1915). The "Bozeman Lake Beds" were raised to group status and defined as the "Bozeman Group" by Robinson (1963).

Dorr and Wheeler (1948) studied the paleontology and strata of the Upper Ruby River Basin and proposed the informal names of "Passamari Formation" for the fine-grained lower sequence and "Madison Valley equivalent" for the coarse-grained upper sequence. Robinson (1963) named the coarse-grained sequence as the "Sixmile Creek Formation" after the type area in Sixmile Creek near Toston, Montana. Peterson (1974) produced a map of the structure and stratigraphy of part of the Upper Ruby River Basin. The Passamari Formation was named as a member of the late Eocene-early Miocene
Renova Formation, and the Miocene Madison Valley equivalent was referred to as the Sixmile Creek Formation.

Hofihnan (1971) described in detail the Tertiary geology, paleoecology, and paleontology of the western Beaverhead Valley area and Petkewich (1972) described in detail the Tertiary geology and paleontology of the eastern Beaverhead Valley area. Monroe (1976) mapped the Tertiary sediments of the northern Ruby River Basin and discussed the paleontology, stratigraphy, and sedimentation of the area. He recognized four distinct mappable members in the Sixmile Creek Formation that he assigned informal names. These members outcrop in the Ruby River Basin and are designated as: Feldspathic Sandstone Member (Tsf), the Metamorphic Fanglomerate Member (Tsm), the Undifferentiated Member (Tsf), and the Quartzite Pebble Conglomerate Member (Tsq).


Garson (1992) mapped the Timber Hill area and discussed the Cenozoic paleovalley, stratigraphy and structural geology.

1.5 Physiography

1.5.1 Location

The Ruby Range and Ruby River Basin region is located about 40 km east of Dillon, Montana and is part of the Rocky Mountain physiographic province (Fig. 1). The Ruby River Basin is located in Beaverhead and Madison counties to the east of the Ruby Range and comprises approximately 675 square kilometers. The lower Beaverhead Valley is located to the west of the Ruby Range, about 12 km northeast of Dillon and comprises approximately 460 square kilometers (Fig. 2). The region is located on the leading edge of the Cordilleran thrust belt and laramide foreland of southwestern Montana and east-central Idaho (Ruppel and Lopez, 1984). The area contains both north and northeast trending mountain ranges and intermontane basins.

1.5.2 Topography

The Ruby River Basin trends northeast for about 45 km and has an average width of 15 km. The basin is bounded by the Greenhorn Range to the northeast, the Snowcrest Range to the southeast and the Ruby and Blacktail ranges to the west. The Ruby and Greenhorn ranges merge at the north end of the basin to form a water gap. The Ruby River Basin contains broad gently sloping pediment surfaces and low rolling hills in the north end of the basin that terminate against the bounding mountain ranges. The pediment surfaces are covered by alluvial fans (fault-line gravels) at the base of the mountain fronts.
The southern end of the Ruby River Basin is characterized by badlands topography and an extensive basaltic lava plain to the southeast on the southern end of the Ruby Range and terminates against the Blacktail Range to the southwest.

The lower Beaverhead Valley has a similar topographic profile. The lower Beaverhead Valley has broad gently sloping pediments that terminate against the Ruby Range to the east. Pediments are covered with a veneer of fault-line gravels at the base of the mountain-front. The western margin of the lower Beaverhead Valley has a massive outcropping of Madison limestone at "Point of Rocks" and the distinctive light brown bluffs of Tertiary sediments to the north (Plate 1).

1.6 Drainage

The present drainage is tributary to the Ruby River that flows northward through the Ruby River Basin. Streams which arise in the bounding mountain ranges drain outward from the main uplifts into the basin. Streams from the western margin of the basin flow eastward, and streams from the eastern margin flow westward through deeply incised canyons of Precambrian and Paleozoic rocks onto gently sloping pediments that empty into the Ruby River. The Blacktail Deer Creek, including the east and west forks, in the lower Ruby River basin drain through a gap between the Ruby and Blacktail ranges and drain into the lower Beaverhead Valley and empty into the northward flowing Beaverhead River. The Big Hole River and the Beaverhead River merge in the Beaverhead Valley.

Geomorphic changes occurred on both the north and south flanks of the Snake River Plain in the wake of the Yellowstone hot spot track during mid-Miocene to Pliocene time (Anders et al, 1989; Anders and Sleep, 1992; Pierce and Morgan, 1992; Fritz and Sears, 1993). Thermal doming, faulting, and deposition of gravels and tephras associated with the Heise Volcanic field cutoff the valley's external drainage and disrupted drainage
patterns on the north flank of the Snake River Plain in southwest Montana and adjacent Idaho in late Miocene time (Ruppel, 1967; Sears et al, 1989; Satterfield et al, 1989; Pierce and Morgan, 1992; Garson, 1992; Fritz and Sears, 1993). The disruption of the drainage appears to coincide with uplift and volcanic activity associated with the Heise volcanic field in the eastern Snake River Plain (Bonnichsen et al, 1989; Garson, 1992; Fritz and Sears, 1993).

Sears et al, (1989) recognized remnants of a Miocene paleovalley with a southwest oriented paleodrainage in southwest Montana. Recent work by Fritz and Sears (1989, 1993) suggest that the headwaters of the paleovalley were in the Belt Supergroup rocks of the Pioneer and Beaverhead mountains. The drainage flowed southeast in a broad basin across what is now the modern Ruby, Blacktail and Centennial mountains, and appear to have flowed across what is now the Snake River Plain. The drainage flowed into the paleovalley from the north into a broad basin approximately 200-300 m deep and several kilometers wide, and flanked by broad bajadas and pediments (Sears et al, 1989; Fritz and Sears, 1993).

Vertebrate fossil data and intercalated tephras derived from the Snake River Plain provide both a structural and stratigraphic datum for bracketing the timing of events associated with the passage of the Yellowstone hotspot track. Vertebrate fossil data, radiometric age dates of intercalated tephras, paleocurrent structures and provenance studies of clasts in fluvial deposits bracket the timing of the drainage reversal and late Cenozoic structural events. Vertebrate fossil data and age dates of tephra samples from the Ruby River Basin and the northwest margin of the Ruby Range bracket the timing of drainage reversal and the structural history of the Ruby River Basin, Beaverhead Valley, and Ruby Range.
Ruby River Basin and Lower Beaverhead Valley study area

Fig. 1. Index map of Ruby River Basin and Beaverhead Valley, SW Montana
Fig. 2. Index map of Ruby River Basin and Lower Beaverhead Valley

Coordinates are UTM zone 11, in meters
Fig. 3. Schematic representation of late Miocene drainage in southwest Montana (Sears et al, 1989).
Fig. 4. Interpretation of late Miocene events influenced by the passing of the Yellowstone hotspot. A: Rivers within paleovalley transport gravel from north and west. Prior to 6.5 Ma volcanic dome rose in path of paleovalley and diverted flow to the east. B: between 6.5 and 4.3 Ma, growth of Heise volcanic field destroys paleovalley. Tuffs and Timber Hill basalt flowed north into Montana. C: Eruption on the Yellowstone plateau deposits Huckleberry Ridge Tuff on paleosurface and Paleovalley deposits. Faulting segments paleovalley into modern valleys and ranges (Fritz and Sears, 1993).
2.1 Pre-Tertiary Rocks

Pre-Tertiary metamorphic, sedimentary, and igneous rocks crop out in the ranges, and locally on the pediment surfaces. Pre-Tertiary rocks range from Archean metamorphic rocks to Late Cretaceous-Tertiary intrusives. The Pre-Tertiary rocks were intensely folded and faulted during the Laramide compression (Heinrich, 1960; Fields and Petkewich, 1967; Okuma, 1971; Karasevich et al, 1981).

Archean metamorphic basement rocks are exposed in the Ruby Range, Blacktail Range, Greenhorn Range, Tobacco Root Mountains, and Highland Mountains. Archean basement rocks belong to the pre-Cherry Creek Group and primarily consists of rocks that are generally foliated parallel to compositional layering, strike northeast and dip 60 to 90 degrees to the northwest (Heinrich, 1960). Pre-Cherry Creek Group rocks consist of leucocratic coarse-grained, banded biotite-hornblende-quartz-feldspar gneiss with minor amounts of biotite schist, marble, amphibolite, metaquartzite and sillimanite-garnet gneiss (Heinrich, 1960; Fields and Petkewich, 1967; Okuma, 1971; Peterson, 1974; Karasevich et al, 1981; Garson, 1992; Ruppel et al, 1993).

Paleozoic and Mesozoic rocks occur in belts within and marginal to the mountain ranges. Paleozoic rocks are dominated by shelf carbonates with minor amounts of shale and sandstone (Fields and Petkewich, 1967). Paleozoic rocks are exposed along the western margin of the Snowcrest range in the southeastern boundary of the basin and in the Pioneer Mountains to the northwest. Lower Paleozoic rocks range in age from middle Cambrian Flathead Sandstone to late Devonian Three Forks Shale and Upper Paleozoic rocks range in age from early Mississippian Madison Group to middle Pennsylvannian Quadrant Formation (Sheedlo, 1984). Mesozoic rocks of the Beaverhead Conglomerate
are predominately clastics of both marine carbonate and terrestrial origin with subordinate carbonates (Fields and Petkewich, 1967). Smaller intrusive bodies of Cretaceous-Tertiary age occur in the mountains throughout the area and range in composition from quartz diorite to granite, with quartz monzonite as the most abundant rock type (Fields and Petkewich, 1967).

2.2 Tertiary Rocks

Tertiary rocks include deposits of the late Eocene-early Miocene Renova Formation and the middle Miocene to Pliocene Sixmile Creek Formation. Collectively, they are known as the Bozeman Group. The Bozeman Group consists of fluvial, lacustrine and eolian deposits that fill the Ruby River Basin. The Bozeman Group has a minimum total thickness of at least 1.5 km (Monroe, 1976, 1981). Five stratigraphic sections were measured on the northwest margin of the Ruby Range and in the Ruby River Basin areas (Fig. 5-14; Appendix 2).

2.3 Tertiary lithology of the Ruby River Basin

2.3.1 Eocene Volcanic Rocks

Satterfield (1989) described a red, densely silicified, cliff-forming tuff unit approximately 150 m thick in the Timber Hill area. The tuff contains variegated liesegang banded material and locally contains well-rounded Belt Supergroup cobbles. The base of the unit is gently dipping and forms a nearly planar contact with the Archean basement rock. It defines the western margin of the paleovalley. The upper contact is covered by the Renova Formation (Garson, 1992). The silicified tuff is similar in appearance to the
Challis Volcanics that are exposed to the east in southern Idaho and southwestern Montana. Silicified tuff also occurs at the contact between the Pre-Tertiary rocks and the Sixmile Creek Formation deposits east of Biltmore Hot Springs (Plate 1).

2.3.2 Renova Formation

The Renova Formation, also known as the lower Bozeman Group was named after the town of Renova, Montana (Kuenzi and Fields, 1971). Kuenzi and Fields (1971) assigned a late Eocene to early Miocene age based on vertebrate fossil evidence from the Jefferson Basin. Similar ages have been assigned to the Renova Formation (lower Bozeman group) by Oelrich (1950), Dorr and Wheeler (1964), and Monroe (1976) based on vertebrate fossil evidence from the Ruby River Basin. Satterfield (1989) obtained a K-Ar age date of 39 ± 3 Ma and Fritz and Wampler (1992) obtained a date of 19.2 ± 0.4 Ma from intercalated tephras.

The Renova Formation is a generally fine-grained lithologic package that is interpreted to consist of low-energy flood plain and lacustrine deposits. The Renova Formation has a total thickness of 600-800 m. The Renova consists of deposits of 70% or more of fine-grained sediments and less than 30% of coarse-grained deposits. The fine-grained nature suggest a low-energy environment within a subdued topography, possibly in a large basin or playa.

The deposits rest unconformably upon Archean basement rocks (Kuenzi and Fields, 1971; Petkewich, 1972; Monroe, 1976). Monroe (1976) recognized three members of the Renova Formation and assigned the following formal stratigraphic names: Climbing Arrow Member (Trc), Dunbar Creek Member (Trd), and Passamari Member (Trp).
2.3.3 Sixmile Creek Formation

The Sixmile Creek Formation, also known as the upper Bozeman Group, was described and named by Robinson (1967) after the type section from Sixmile Creek near Toston, Montana. The type section is more than 1200 m thick and ranges from early to late Miocene. The middle Miocene to Pliocene Sixmile Creek Formation overlies the Renova Formation with an angular unconformity. It is a generally unlithified, coarse-grained, well-rounded conglomerate with subordinate sandstone, silt, limestone, and fluvially deposited tephras. Monroe (1976) described the Sixmile Creek Formation as consisting of approximately 49% conglomeratic sandstone, 28% conglomerate, 15% tephra, 5% siltstone, and 3% limestone. The Sixmile Creek Formation rests directly upon Archean rocks west of Timber Hill (Garson, 1992), but overlies the Renova Formation in the Upper Ruby River Basin.

Monroe (1976) assigned informal names to four distinct mappable members: Feldspathic Sandstone Member (Tsf), Undifferentiated Member (Tsu), Metamorphic Fanglomerate Member (Tsm), and Quartzite Pebble Conglomerate Member (Tsq). The members are separated in section by friable siltstone deposits. The top of the Sixmile creek Formation is locally capped by the 1.9 Ma Huckleberry Ridge Tuff along Robb Creek, hot spring limestone tufa deposits along the northwestern margin of the Upper Ruby River Basin, and the 6 Ma Timber Hill Basalt along the western margin.

2.3.3.1 Feldspathic Sandstone Member (Tsf)

The feldspathic sandstone member consists of medium- to coarse-grained feldspathic sandstone, conglomerate and tephra that grades laterally into the metamorphic fanglomerate and quartzite pebble conglomerate members. The sandstones are tuffaceous
and contain chert, quartz, feldspar, biotite, and volcanic rock fragments. The member is poorly to moderately lithified with calcareous cement. This member crops out in the Timber Hill area (Garson, 1992).

### 2.3.3.2 Undifferentiated Conglomerate Member (Tsu)

The undifferentiated member is the base of the Sixmile Creek Formation in the lower Ruby River Basin. It consists of beds of rounded to well-rounded, clast and matrix-supported pebble and cobble conglomerate, and is interbedded with friable sandstone, siltstone, tephra, and limestone. The member is poorly to moderately lithified and weakly cemented with calcite.

Clasts are derived from Precambrian Belt Supergroup and Paleozoic rocks. The Precambrian Belt Supergroup clasts consist of red and green argillite, and are derived from the Belt Supergroup rocks in the Pioneer and Highland Mountains to the northwest. The Paleozoic clasts consist of carbonate rocks of the Mission Canyon Formation and quartzite of the Quadrant and Amsden Formations. Other clasts are pegmatite and vein quartz. Drainage flow direction was northwest to southeast as determined from observations of clast imbrication and trough cross-bed foreset laminations of sandstone and siltstone interbeds. Vertebrate fossil evidence indicates a Barstovian (~16-11.5 Ma) to Clarendonian (~11.5-8 Ma) land mammal age (Oelrich, 1950; Dorr and Wheeler, 1964; Hoffman, 1971; Petkewich, 1972; Monroe, 1976). A tephra sample (BT-1) from the undifferentiated member near the base of the East Fork of Blacktail Deer Creek measured section yields a fission-track age date of 11.3 ± 0.38 Ma, and another (BT-3) near the top of the member yields an age of 10.53 ± 0.35 Ma (Table 1).
2.3.3.3. Metamorphic Fanglomerate Member (Tsm)

The metamorphic fanglomerate member is the base of the Sixmile Creek Formation in the Upper Ruby River Basin and appears to be time-equivalent with the undifferentiated member. It consists of beds of subangular to subrounded, clast and matrix-supported pebble and cobble conglomerate, and is interbedded with friable sandstone, siltstone, tephra, and limestone. The member is poorly to moderately lithified and weakly cemented with silica.

The majority of clasts appear to be locally derived and consist of Archean metamorphic basement rocks. The clasts are primarily leucocratic banded biotite-hornblende-quartz-feldspar gneiss, sillimanite-garnet, and biotite schist, and appear to be derived from the pre-Cherry Creek Group. Other clasts include minor amounts of pegmatite, volcanic fragments, and red and green argillite. The member lacks definable paleocurrent structures. It appears that this fanglomerate may have prograded basinward from the Tobacco Root Mountains or the Ruby and Greenhorn ranges.

The member grades laterally into the undifferentiated member. Vertebrate fossil evidence indicates a Barstovian (~16-11.5 Ma) to Hemphillian (~8-4.5 Ma) land mammal age (Dorr and Wheeler, 1964; Monroe, 1976). A fission-track age date obtained from a tephra sample (BG-2) near the top of the Barton Gulch measured section yields a date of 11.6 ± 0.39 Ma, however, this age-date occurs in a mixed population of glass shards and is considered unreliable (Table 1).
2.3.3.4 Quartzite Pebble Conglomerate Member

The quartzite pebble conglomerate member is the youngest and overlies the other members. It consists of well-rounded, clast- and matrix-supported pebble and cobble conglomerate, and is interbedded with friable sandstone, siltstone, tephra, and limestone hot spring deposits. The member is poorly to moderately lithified and weakly cemented with silica.

Drainage flow direction was to the north-northeast based on clast provenance and paleocurrent structures. Clasts are derived from the southwest and include brown Quadrant quartzite from the Tendoy Mountains in southwestern Montana, pink Swauger Quartzite from the Lemhi Range and black chert with white quartz veins of the Milligan chert from the Pioneer Mountains of central Idaho (Fritz and Sears, 1993). Clasts are strongly imbricated northward and three dimensional exposures of trough cross-beds show foreset laminations indicating a northward-flowing drainage.

The member is locally capped by the 1.8 Ma Huckleberry Ridge Tuff, hot spring limestone tufa deposits, and the 6 Ma Timber Hill basalt. Vertebrate fossil evidence indicates a Clarendonian (~11.5-8 Ma) land mammal age to Pliocene time (Dorr and Wheeler, 1964; Hoffman, 1971; Petkewich, 1972; Monroe, 1976). A 7.76 ± 0.27 Ma fission-track age date was obtained from a tephra sample (BT-4) near the base of the quartzite pebble conglomerate in the Blacktail Deer Creek measured section, and a 5.83 ± 0.18 Ma age was obtained from a tephra at the base of the Timber Hill basalt (Table 1).
2.3.3.5 Timber Hill basalt (Thb)

The Timber Hill basalt is a dark brown to black, fine-grained olivine tholeiite. Exposures of the Timber Hill basalt are widespread in the lower Ruby River Basin and trends northeast along the western margin of the Upper Ruby River Basin. Stretched vesicles show a northeast-southwest orientation. The Timber Hill basalt is traceable as far south as Lima, Montana. The basalt may have originated from the Blue Creek Caldera in the Heise volcanic field on the eastern Snake River Plain (Fritz and Sears, 1993).

2.3.3.6 Quaternary-Pliocene hot spring deposits (Ths)

Widespread gray colored hot spring deposits are exposed along the range-front faults along the western margin of the Ruby River Basin, the hills south of the East Fork of Blacktail Deer Creek, and to a lesser degree along the Greenhorn range-front fault on the south side of Barton Gulch. These deposits appear to form along reactivated range-front faults along the margins of the basin.

2.4. Quaternary Alluvium (Qal)

Quaternary alluvium deposits are widespread and occupy the low-lying areas of the Ruby River Basin. The alluvium deposits are incised by modern streams. Thickness is undetermined due to the lack of exposure of underlying bedrock. Other Quaternary deposits include fault-line gravels that overlie contacts of the mountain ranges and pediment slopes.
2.5 Tertiary Lithology of the Lower Beaverhead Valley

2.5.1 Renova Formation

The Renova Formation crops out along the bluffs at the western margin of the Beaverhead Valley north and west of the Cretaceous limestone at "Point of Rocks" (Plate 1). The Renova Formation is generally the same as described in the Upper Ruby River Basin. The fine-grained nature of the deposits indicate a low-energy depositional environment within a subdued topography, possibly in a large basin or playa, and therefore is interpreted to be part of the same depositional basin. The deposits rest unconformably upon Paleozoic and Mesozoic rocks (Kuenzi and Fields, 1971; Petkewich, 1972). The Passamari member (Trp) is the most abundant member, with minor outcrops of the Dunbar Creek member (Trd).

2.5.2 Sixmile Creek Formation

2.5.2.1 Undifferentiated member (Tsu)

The undifferentiated member is the base of the Sixmile Creek Formation in the lower Beaverhead Valley. The member is the same as described in the Upper Ruby River Basin. Drainage flow direction was northwest to southeast as determined from clast imbrication and trough cross-bed foreset laminations of sandstone and siltstone interbeds. Vertebrate fossil evidence indicates a Barstovian (~16-11.5 Ma) to Clarendonian (~11.5-8 Ma) land mammal age (Hoffman, 1971; Petkewich, 1972). A tephra sample (MSD-2) from near the top of the undifferentiated member of the Mule Shoe Ditch measured
section yields a fission-track age date of $9.83 \pm 0.35$ Ma, however, it is from a mixed population of shards (Shane, 1995) (Table 1).

2.5.2.2 The Quartzite Pebble Conglomerate

The quartzite pebble conglomerate member is the youngest and overlies the undifferentiated member. It is the same as described in the Upper Ruby River Basin. The member crops out along the northwestern margin of the Ruby Range, north of McHessor Creek. Drainage flow direction was to the north-northeast based on clast provenance and paleocurrent structures. Vertebrate fossil evidence indicates a Clarendonian (~11.5-8 Ma) to Hemphillian (8-4.5 Ma) land mammal age (Dorr and Wheeler, 1964; Monroe, 1976).

2.6 Quaternary (Qal)

Quaternary alluvium deposits are widespread and occupy the low-lying areas of the Beaverhead Valley. The alluvium deposits are incised by the modern Big Hole and Beaverhead rivers. Thickness is undetermined due to the lack of exposure of underlying bedrock. Other Quaternary deposits include fault-line gravels that overlie contacts of the mountain ranges and pediment slopes.
BARTON GULCH

Meters

Sixmile Creek Formation

Quartzite Pebble Conglomerate Mbr.

Vertebrate fossils:

Eucastor sp.¹ (Pliocene)
Alticamelus sp.¹ (Pliocene)

Merychippus Sp.² (E. Barstovian)

BG-2 (11.6 ± 0.39 Ma)³

2. Vertebrate fossils cited by Monroe, 1976
3. Fission-track date from Shane, 1995 (Pers. comm.)

Fig. 5. Barton Gulch measured section. included are vertebrate fossil data and radiometric ages.
Vertebrate fossils:
Merychippus sp.\(^1\) (E. Barstovian)
Testudo Primaeva\(^2\)
(E. Barstovian - L. Hemingfordian)

Angular unconformity
Vertebrate fossil:
Oxydactylus Longipes sp.\(^1\)
(Arikareean)


Fig. 6. Belmont Park Ranch measured section. Included are vertebrate fossil data.
EAST FORK OF BLACKTAIL DEER CREEK

Fig. 7. East Fork of Blacktail Deer Creek measured section. Included are radiometric ages of intercalated tephras (this thesis).

1. Fission-track age from Shane, 1995 (pers. comm.).
### BILTMORE ROAD

<table>
<thead>
<tr>
<th>Meters</th>
<th>Sixmile Creek Formation</th>
<th>Vertebrate fossil:</th>
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<tr>
<td></td>
<td>Undifferentiated Conglomerate Mbr</td>
<td><em>Pliohippus sp.</em> (E. Barstovian)</td>
</tr>
<tr>
<td></td>
<td>Renova Formation</td>
<td>Vertebrate fossils:</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Mesohippus sp.</em> (Chadronian - Arikareean)</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Leptomeryx sp.</em> (Chadronian - Arikareean)</td>
</tr>
</tbody>
</table>


---

Fig. 8. Biltmore Road measured section. Included are vertebrate fossil data.
Vertebrate fossils:
*Dipoides sp.*\(^1\) (Pliocene)

MSD-2 \((9.83 \pm 0.35 \text{ Ma})\)^2

Vertebrate fossil:
*Pliohippus sp.*\(^1\) (E. Barstovian)

---

2. Fission-track age from Shane, 1995 (pers. comm.)

---

Fig. 9. Mule Shoe Ditch measured section. Included are vertebrate fossil and radiometric age data.
Fig. 10. Stratigraphic correlation chart of measured sections. Tr – Renova Formation (undivided), Tsm – Metamorphic Conglomerate Member, Tsu – Undifferentiated conglomerate Member, Tsq – Quartzite Pebble Conglomerate Member.

* Measured by Garson, 1992
Fig. 11. Undifferentiated Conglomerate Member (Tsu) near "Point of Rocks" in lower Beaverhead Valley. Contains clasts of Belt Supergroup and Paleozoic carbonate rocks.

Fig. 12. Metamorphic Fanglomerate (Tsm) overlain by tephra, Barton Gulch.
Fig. 13. Quartzite Pebble Conglomerate Member (Tsq), Barton Gulch. Contains clasts of Swauger quartzite and Milligan chert.

Fig. 14. Tephra (BG-2) near top of Metamorphic Fanglomerate Member, Barton Gulch.
<table>
<thead>
<tr>
<th>SAMPLE</th>
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<th>METHOD</th>
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<th>AGE (Ma)</th>
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<tr>
<td>NG-35*</td>
<td>tephra</td>
<td>K-Ar</td>
<td>Robb Creek</td>
<td>1.8 +/- 0.1</td>
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<tr>
<td>TH-147-90K*</td>
<td>basalt</td>
<td>K-Ar</td>
<td>Timber Hill</td>
<td>5.9 +/- 0.2</td>
</tr>
<tr>
<td>SWP-89-111*</td>
<td>basalt</td>
<td>K-Ar</td>
<td>Timber Hill</td>
<td>6.3 +/- 0.2</td>
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<tr>
<td>BG-2</td>
<td>tephra</td>
<td>fission-track</td>
<td>Barton Gulch</td>
<td>11.6 +/- 0.39</td>
</tr>
<tr>
<td>BT basal tuff</td>
<td>tephra</td>
<td>fission-track</td>
<td>Blacktail Deer Creek</td>
<td>5.83 +/- 0.18</td>
</tr>
<tr>
<td>BT-4</td>
<td>tephra</td>
<td>fission-track</td>
<td>E. Fork Blacktail Deer Crk.</td>
<td>7.76 +/- 0.27</td>
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<tr>
<td>BT-3</td>
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<td>fission-track</td>
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<tr>
<td>BT-2</td>
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<td>10.53 +/- 0.35</td>
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<tr>
<td>BT-1</td>
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<td>fission-track</td>
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<tr>
<td>MSD-2</td>
<td>tephra</td>
<td>fission-track</td>
<td>E. Fork Blacktail Deer Crk.</td>
<td>9.83 +/- 0.35</td>
</tr>
</tbody>
</table>

Table 1. Radiometric age dates from Shane, 1995, University of Toronto (pers. comm.) and ages cited in Garson, 1992*.
CHAPTER 3

LATE CENOZOIC STRUCTURE

3.1 Ruby River Basin Faults and Folds

3.1.1 Range-Front Normal Faults

The Ruby River Basin is a horst and graben structure. Late Cenozoic sedimentary rocks are down-faulted against Pre-Tertiary rocks (Fig. 15). The Ruby River Basin is bounded to the east by the Greenhorn and Snowcrest range-front normal faults, to the west by the East Ruby range front fault, and to the south by the Blacktail fault (Plate 1).

Seismic data cited by Ferguson (1989) indicates that the maximum depth to Archean basement rock in the northern part of the basin is about 3140 m and 1640 m in the southern part of the basin. Steep gravity gradient along the eastern basin margin indicates that the eastern bounding wall slopes are steeper than those on the western margin (Ferguson, 1989; Hanna, et al, 1993). The steep gravity gradients are interpreted to indicate the presence of faults.

3.1.1.1 East Ruby Fault

The East Ruby fault trends northeast along the contact between Tertiary basin fill and the Precambrian basement on the western margin of the Ruby River Basin. The fault appears to be offset by as much as 650 m in the Sweetwater Creek area. The fault trace is characterized by warm springs and calcareous hot spring deposits.
3.1.1.2 Greenhorn-Snowcrest Range Front Fault System

The Greenhorn-Snowcrest ranges trend north-south along the contact between the Tertiary basin fill and Pre-Tertiary rock. The fault contacts are generally obscured by "overlap" gravels derived from the adjacent ranges.

3.1.2 Northwest Trending Normal Faults

Northwest trending normal faults traverse the Ruby River Basin, the Ruby Range, and cross-cut the East Ruby fault. Sheedlo (1984) suggests that these faults are Proterozoic structures that have been reactivated as normal faults.

3.1.2.1 Garden Creek - Peterson Creek Faults

Garden Creek and Peterson Creek faults trend northwest-southeast from the south end of the Ruby Reservoir and appear to merge in the Ruby Range. The fault contact continues across the Ruby Range along McHessor Creek on the northwest margin of the Ruby Range, and into the Beaverhead Valley. They can be traced for at least 33 km and are down-faulted to the northeast. The amount of offset is undetermined.

3.1.2.2 Stone Creek Fault

Stone Creek fault trends northwest-southeast for more than 40 km across the Ruby River Basin and Ruby Range. It extends from the Snowcrest Range on the southeast to the northwest margin of the Ruby Range. The fault can be traced northwest across the Ruby Range and along Stone Creek on northwest margin of the Ruby Range, and may continue beneath the pediment surface in the Beaverhead Valley.
Stone Creek fault is a high angle fault that is down-faulted to the southwest. It is a left-lateral dip-slip fault that offsets the East Ruby fault by at least 5.5 km. The fault was reactivated as a high angle normal fault with at least 650 m of offset. North of Timber Hill, the fault "scissors" or changes its sense of movement and is down-faulted to the northeast. It was reactivated with a reversed sense of throw (Monroe, 1976; Garson, 1992).

3.1.2.3 Cottonwood Creek Fault

Cottonwood Creek Fault trends northwest-southeast for at least 7.5 km across the Ruby Range along Cottonwood Creek. The fault is down-faulted to the northeast and the amount of offset is undetermined.

3.1.2.4 Sweetwater Creek Fault (Timber Hill Fault)

Sweetwater Creek fault trends northwest-southeast across the Ruby River Basin from the Snowcrest Range to the Ruby Range, off-setting the East Ruby fault 2 km. The Sweetwater fault is located south of Stone Creek fault. The fault can be traced northwest across the Ruby Range.

The post-Pliocene fault is interpreted to be down-faulted to the northeast with 250 m of offset, however, gravity modeling suggests movement is dip-slip with displacement down to the southwest. A gravity anomaly high in the area between Stone Creek and Sweetwater Creek faults may indicate that the basin is more shallow due to an uplifted block (Ferguson, 1989; Hanna et al, 1993). After eruption of the Timber Hill basalt, the fault was reactivated as a normal fault with at least 250 m of offset.

The South Timber Hill fault is a high angle fault southwest of Timber Hill. The fault has less than 100 m of offset (Garson, 1992). The fault can be traced for at least 20
km from South Timber Hill to the south end of Hogback Mountain in the Snowcrest Range. Movement dip-slip with displacement down to the northeast.

3.1.2.5 Blacktail Fault

The Blacktail fault is a steeply dipping, northwest trending range-front normal fault along the northeast flank of the Blacktail Range. The fault is down-faulted to the northeast. Ferguson (1989) suggests that this fault may coincide with the southern terminus of the Ruby River Basin.

3.2 Folds

3.2.1 Jack Creek, Sweetwater Syncline, and Blacktail Synclines

The Jack Creek syncline is located on the east side of the basin along Jack Creek. The axis trends N 75 W and gently plunges east. The Sweetwater syncline is located on the west side of the basin, west of Sweetwater Creek. It roughly parallels the trend of the basin axis at N 60 E. The Blacktail Deer Creek syncline is located between the middle and east forks of Blacktail Deer Creek. It trends N 48 W and gently plunges southeast. The folds are broad and may result from differential compaction.

3.2.2 Ledford Anticline

The Ledford anticline parallels the basin axis and trends northeast-southwest along the length of the basin. The axis trends about N 36 E. The fold is broad and the limbs are gently dipping. Excellent exposures along the bluffs are visible from a distance on the north side of the East Fork of Blacktail Deer Creek (Fig. 14).
3.3 Lower Beaverhead Valley Faults

3.3.1 Range Front Normal Fault

The Beaverhead Valley is a half-graben, down-faulted to the west, bounded by the West Ruby Range normal fault to the east. Late Cenozoic sedimentary rocks are down-faulted against Precambrian basement rock. Steep gravity and magnetic gradients are interpreted to indicate the presence of the fault (Hanna, et al, 1993). Tertiary deposits on the west side of the basin gently dip toward the east (Plate 2).

3.3.2 Northwest Trending Normal Faults

Several northwest trending normal faults in the Ruby River Basin and the Ruby Range continue northwestward into the Beaverhead Valley.

3.3.2.1 McHessor Creek Fault

McHessor Creek fault is the northwestward continuation of Garden Creek and Peterson Creek faults. It trends northwest-southeast along McHessor Creek. It is down-faulted to the northeast and offsets deposits of the quartzite pebble conglomerate member of the Sixmile Creek formation against the undifferentiated member. The fault may continue westward across the lower Beaverhead Valley and is expressed as the contact between the Paleozoic limestone of Beaverhead Rock and the Renova formation. The amount of offset is undetermined.
3.3.2.1 Stone Creek Fault

Stone Creek fault trends northwest-southeast for more than 40 km across the Ruby River Basin and Ruby Range, and continues northwestward into the lower Beaverhead Valley along Stone Creek and may continue beneath the pediment surface in the lower Beaverhead Valley. Stone Creek fault is a high angle fault that is down-faulted to the southwest. It is a left-lateral dip-slip fault. The amount of offset is undetermined.
Fig. 15. Preliminary subcrop map of the Miocene Sixmile Creek Formation, SW Montana showing graben structures (Sears et al, 1995).
CHAPTER 4
LATE CENOZOIC GEOLOGIC HISTORY

4.1 Late Eocene - Early Miocene

The fine-grained nature of the sedimentary deposits of the Renova Formation indicate a subdued topography in a lacustrine or flood plain environment. The deposits accumulated in a large, shallow, enclosed basin or playa. A radiometric K-Ar age of 19.2 ± 0.4 Ma (Garson, 1992), and vertebrate fossils may provide evidence of a younger limit in the Arikareean (29-20 Ma) (Monroe, 1976).

4.2 Middle Miocene - Late Miocene

The Renova Formation deposits were faulted, tilted, eroded, and preserved in the Ruby River graben and the Beaverhead half-graben. The contact forms an angular unconformity with the overlying Sixmile Creek Formation deposits. The coarse-grained deposits of Sixmile Creek Formation, including locally derived clasts of the metamorphic fanglomerate member (Tsm) and the undifferentiated conglomerate member (Tsu), along with radiometric ages of intercalated tephras, and vertebrate fossil data are evidence that extension began in the late-early Miocene.

The timing of extension coincides with the initiation of Basin and Range extension (Fritz and Sears, 1993; Sears et al, 1995). Intercalated tephras are derived from vents on the Snake River Plain (Fig. 16). Ages of most tephras appear to coincide with the ages of the Picabo and Twin Falls volcanic fields (Sears et al, 1995; Shane, 1995). The basal units of the Sixmile Creek Formation appear to be about 16 - 17 Ma (Monroe, 1976; Fields et al, 1985).
4.2.1 Metamorphic Fanglomerate Deposits

A fission track age of an intercalated tephra in the metamorphic fanglomerate member (Tsm) dates at $11.6 \pm 0.39$ Ma. Vertebrate fossils range in age from Early Barstovian ($16 - 11.5$ Ma) to Hemphillian ($8 - 4.5$ Ma). Cobbles are locally derived from the Ruby, Greenhorn, and Snowcrest ranges, and are preserved debris flows.

4.2.2 Undifferentiated Conglomerate Deposits

Fritz and Sears (1993) cite a $^{40}{\text{Ar}} - ^{39}{\text{Ar}}$ radiometric age of $15.7 \pm 1.3$ Ma for the Tuff of Spring Brook. A fission track age of $7.76 \pm 0.27$ Ma was obtained from tephra at the top of the undifferentiated member. Vertebrate fossils range in age from Early Barstovian ($16 - 11.5$ Ma) to Clarendonian ($11.5 - 8$ Ma). Discrete tephras crop out along the length of the Ruby River basin, and tephras with mixed age populations crop out in the lower Beaverhead Valley possibly in a different depositional graben system (Shane, 1995).

Paleocurrent structures indicate that the drainage of the paleovalley flowed southeast, depositing distinctive clasts of Belt Supergroup rocks derived from the Pioneer and Highland mountains. Trough axes of interbedded sandstone and cobble imbrication show that the paleovalley drained to the south. Remnants of this paleovalley are preserved on the basin margins and on top of the Ruby Range.
4.3 Late Miocene - Quaternary

Deposition continued throughout the late Miocene and Pliocene. The Metamorphic Fanglomerate (Tsm) deposits intertongue both the undifferentiated member (Tsu) and quartzite pebble conglomerate member (Tsq). Clast provenance and paleocurrent structures provide evidence of a major drainage disruption. The quartzite pebble conglomerate member contains distinctive cobbles of Swauger quartzite from the Lemhi Range and Milligan chert derived from the Pioneer Mountains of central Idaho. Paleocurrent structures indicate drainage direction reversed to a northward flow direction.

Doming of the Heise volcanic field appears to have disrupted drainage patterns of the Paleo-valley. The drainage reversal may have occurred sometime after the eruption of the 7.76 ± 0.27 Ma tephra and before the eruption of the 6 Ma Timber Hill basalt that locally caps the member. The Timber Hill basalt is derived from the Heise volcanic field, possibly the Blue Creek Caldera. This time bracket coincides with the age of the Heise volcanic field.

The 1.9 Ma Huckleberry Ridge Tuff crops out near the top of the member at Robb Creek. The eruption of the Huckleberry Ridge Tuff coincides with the age of the Huckleberry Ridge Caldera (Fig. 16). Change in the stress vector field associated with doming of the Yellowstone plateau appears to have initiated left-lateral strike-slip faulting. Northwest-trending faults traverse the Ruby Range, Ruby River Basin, and lower Beaverhead Valley. They offset the East Ruby Fault, Sixmile Creek Formation deposits, and possibly the Timber Hill basalt.
Fig. 16. Location of study area in relation to the Yellowstone hotspot track with ages of major calderas (modified after Morgan and Hackett, 1989).
CHAPTER 5
CONCLUSIONS

Basin deposition of fine-grained Renova Formation began in southwestern Montana during late Eocene - late Oligocene time. Vertebrate fossil and radiometric age data suggest an upper limit of about 20 Ma. Basin-and-range style extension began in southwestern Montana in middle Miocene time. Renova Formation deposits were tilted, eroded, and down-faulted. The Renova Formation deposits were overlain by coarse-grained Sixmile Creek Formation deposits that accumulated in fluvial and alluvial systems within the grabens. The angular unconformity between the Renova Formation and Sixmile Creek Formation marks the onset of basin-and-range faulting in southwest Montana.

Vertebrate fossil data and radiometric age dates of intercalated tephras derived from vents on the Snake River Plain indicate extension began at about 16-17 Ma. Northeast-oriented range-front faulting along the flanks of the Ruby Range segmented the basin into northeast-trending grabens. The Ruby River Basin is a graben down-faulted between the Ruby and Greenhorn-Snowcrest ranges, and the Beaverhead Valley is down-faulted to the west on the west flank of the Ruby Range.

Clast provenance, paleocurrent structures, vertebrate fossil data, and radiometric age data show a late Miocene paleovalley with southeast oriented drainage. Cobbles of Belt Supergroup rocks are derived from the Highland and Pioneer mountains to the north and west. These deposits intertongue metamorphic fanglomerate deposits derived from the rising Ruby and Greenhorn ranges. Remnants of coarse fluvial deposits are preserved on the tops of the Ruby and Snowcrest ranges. Intercalated tephras appear to be fluvially deposited in broad channels along the graben axes. Age dates of the tephras coincide with the ages of the Picabo and Twin Falls volcanic fields at about 9 - 12 Ma.
Doming of the Heise volcanic field at about 6.5 Ma disrupted and reversed the drainage northward. Clasts derived from the Lemhi Range and Pioneer Mountains of central Idaho, along with paleocurrent structures, vertebrate fossil, and radiometric ages of intercalated tephas show that the drainage was disrupted and reversed at about 6 - 8 Ma.

Northwest oriented left-lateral dip-slip faulting segmented the grabens. The faulting offset the East Ruby range-front fault, as well as, the 6 Ma Timber Hill basalt. A change in the stress vector field associated with the doming of the Yellowstone Plateau at about 2 Ma may have caused major movement on northwest-trending faults cross-cutting the grabens.
REFERENCES


Hayden, F.V., 1872, Preliminary report of the geological survey of Montana and portions of adjacent territories, being a fifth annual report of progress; Washington.


APPENDIX 1

Access information for AutoCAD R.12 plate drawings (back pocket).
Plate 1 is on floppy disk 1, and Plates 2 and 3 are on disk 2. The drawings were digitized with "ROOTS" digitizing software (shareware) from Harvard University. The plates were constructed with AutoCAD R.12 for windows software. The plates may be changed to any scale using the "LTscale" or "Scale" commands, "Scale" command from the "Modify" drop-down menu bar, or by selecting the appropriate scale for the .PLT file for hard copy plots. Line widths are thickened for visual effects on-screen and may be changed for on-screen viewing or hard copy plots by using the "Change Properties" dialogue box under the "Modify" drop-down menu bar.

Contents:

Disk 1: Plate1.dwg file is a map of the lower Beaverhead Valley and Ruby River Basin study areas. The map is a compilation of field maps (this thesis) and the thesis map by Garson (1992). The map contains measured section and tephra sample site locations, and Miocene vertebrate fossil data cited by Monroe (1976)

Disk 2: Plate2.dwg file has cross sections of the study areas. The cross sections show the geometry of the half-graben structure of the lower Beaverhead Valley and the graben structure of the Ruby River Basin.

Plate3.dwg file is a fence diagram of the Ruby River Basin. Thicknesses are based on stratigraphic correlations. Stratigraphic sections are not completely exposed in the field, therefore, thicknesses are estimates.

Access Procedure:

Plate drawings were constructed with AutoCAD R.12 for windows software and are saved as .DWG files. To access the AutoCAD files, use the following procedure:

1. Launch AutoCAD R. 12 for windows.

2. Select "File", "Open" from the menu bar. The "Open Drawing" dialogue box will appear on screen. The drives and directories are listed in the right-hand column and files are listed in the left-handed column.

3. Select either drive a: or b: depending on floppy drive bay, select the appropriate file by double clicking on the name of the drawing with the mouse, or select the file name and click on "OK" with the mouse. The drawing will appear on-screen. Any area can be viewed for closer inspection by using the "Zoom" and "Window" commands.
APPENDIX 2

Measured sections. Included are field descriptions supplemented with vertebrate fossil data and radiometric age dates of tephra samples.

BARTON GULCH

Barton Gulch Section. This section is located in the Upper Ruby Basin approximately 13 km south of Alder. Exposures are measured (west to east) on the north side of Barton Gulch. This section includes exposures of the Metamorphic Fanglomerate (Tsm) and Quartzite (Tsq) members of the Sixmile Creek Formation. The Quartzite Member contains clasts of pink Swauger quartzite, brown Quadrant quartzite, and quartz-veined black Milligan chert with white quartz veins. The member also contains vertebrate fossils of Eucastor sp.¹ and Alticameîus ¹. The Metamorphic Fanglomerate Member contains clasts of Precambrian Cherry Creek metamorphic rocks, pegmatite, and limestone, and vertebrate fossils of Meryhippus seversus sp.². The section is covered at the base. (SE 1/4, sec. 12. T.7S, R. 4W. to SE 1/4, sec, 15, T.7S, R.4W).

Sixmile Creek Formation

Quartzite Conglomerate Member

1. 7.2 meters Conglomerate. Imbricated northward, clast-supported, cobble size, subangular clasts of quartzite and gneiss.
2. 3.5 meters Covered.
3. 13.6 meters Sandstone. Light brown, tuffaceous with minor lenses of quartzite conglomerate and tephra.
4. 6.8 meters Tephra. White and fine-grained with trough crossbeds. Sample BG-3.
5. 6.8 meters Tuffaceous sandstone. Minor quartzite.

37.9 meters Total
### Metamorphic Fanglomerate Member

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<th>Thickness (m)</th>
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</thead>
<tbody>
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<td>6</td>
<td>4.5</td>
<td>Conglomerate. Matrix-supported, pebble size clasts of gneiss and quartzite.</td>
</tr>
<tr>
<td>7</td>
<td>6.2</td>
<td>Tephra. White, cross-bedded. Sample BG-2 (11.6 ± 0.39 Ma)(^{3}).</td>
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<tr>
<td>8</td>
<td>2.0</td>
<td>Covered.</td>
</tr>
<tr>
<td>9</td>
<td>19.0</td>
<td>Tuffaceous sandstone. Light tan, grades into coarse-grained sandstone.</td>
</tr>
<tr>
<td>10</td>
<td>5.7</td>
<td>Tephra. White to light gray, trough cross-beds. Sample BG-1.</td>
</tr>
<tr>
<td>11</td>
<td>62.3</td>
<td>Alternating beds of sandstone and conglomerate. Base of section.</td>
</tr>
<tr>
<td></td>
<td>139.4</td>
<td>Total</td>
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</table>

3. Shane, 1994 (pers. comm.).
BELMONT PARK RANCH

Belmont Park Ranch. The section is located approximately 11.5 km southwest of Barton Gulch. Exposures are measured (south to north) on the west side of the Upper Ruby Basin flood plain, north of Sweetwater Creek road. This section mostly contains the Metamorphic Fanglomerate Member (Tsm) of the late Miocene-middle Pliocene Sixmile Creek Formation unconformably overlies the Passamari Member of the late Eocene-middle Oligocene Renova Formation (Trp). The Metamorphic Fanglomerate Member contains vertebrate fossils of *Leptarctus primus*¹, *Teleocerus* sp.¹, *Merychippus* sp.² and *Testudo primaeva*³.

(NE 1/4, sec. 13, T.8S, R.5W to NW 1/4, sec. 1, T.8S, R.5W).

Sixmile Creek Formation

Metamorphic Fanglomerate Member

1. 2.2 meters Sandstone. Light brown and friable with scattered pebble size clasts of quartzite and gneiss. Top of section.
2. 129.4 meters Covered.
3. 29.1 meters Sandstone. Gray and friable.
4. 1.0 meters Limestone. Light gray with scattered pebble size clasts.
5. 33.5 meters Sandstone and Conglomerate. Alternating beds of sandstone and conglomerate. Conglomerate is contains angular to subangular, pebble to cobble size clasts of gneiss, schist, pegmatite, quartzite, granite and mudstone.
6. 13.0 meters Conglomerate and sandstone. Same as 5, but with tephra lenses.
7. 9.8 meters Tephra. Gray, trough cross-beds and friable. Sample SW-1.
8. 18.7 meters Covered.
9. 6.9 meters Conglomerate. Pebble size, angular to subangular clasts of gneiss, schist, pegmatite and quartzite.
<table>
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<td>8.1 meters</td>
<td>Sandstone. Light brown, cross-bedded and friable.</td>
</tr>
<tr>
<td>11.</td>
<td>10.0 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>12.</td>
<td>22.7 meters</td>
<td>Sandstone. Scattered clasts.</td>
</tr>
<tr>
<td>13.</td>
<td>0.7 meters</td>
<td>Conglomerate. Pebble size, angular to subangular, quartzite, pegmatite, gneiss, granite, mudstone and limestone.</td>
</tr>
</tbody>
</table>

278.1 meters Total

Renova Formation

Passamari Member

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.</td>
<td>17.0 meters</td>
<td>Siltstone. Light olive green, thinly laminated to thinly bedded.</td>
</tr>
<tr>
<td>24.</td>
<td>9 meters</td>
<td>Siltstone. Light brown, thinly laminated to thinly bedded. Base of section.</td>
</tr>
</tbody>
</table>

320.0 meters Total

EAST FORK OF BLACKTAIL DEER CREEK

This section is located approximately 42 km southeast of Dillon. This section is measured (east to west) from exposures on the north side of East Fork of Blacktail Deer Creek and can be reached by driving south from Dillon on Blacktail Deer Creek Road. Turn left on East Fork of Blacktail Deer Creek Road and drive 5 km east. This section contains exposures of the Quartzite Conglomerate (Tsq) and Undifferentiated Conglomerate (Tsu) members of the Sixmile Creek Formation. The Quartzite Conglomerate Member contains clasts of pink Swauger quartzite, brown Quadrant quartzite, and black Milligan chert with white quartz veins. The Undifferentiated Conglomerate Member contains clasts of quartzite, limestone, dolomite, mudstone, red and green argillites. (NE 1/4, sec. 5 T.11S, R.6W, to NW 1/4, sec.4, T.11S, R.6W).

Sixmile Creek formation

Quartzite Conglomerate Member

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0 meter</td>
<td>Timber Hill Basalt (Thb), 6 Ma. Tuff at base of basalt is dated at 5.83 ± 0.18 Ma (^1).</td>
</tr>
<tr>
<td>2</td>
<td>63.0 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>3</td>
<td>44.2 meters</td>
<td>Poorly exposed alternating beds of conglomerate, sandstone and tephra. Top of section.</td>
</tr>
<tr>
<td>4</td>
<td>8.7 meters</td>
<td>Conglomerate. Rounded cobble size clasts of quartzite chert and minor limestone, imbrication to the south.</td>
</tr>
<tr>
<td>5</td>
<td>4.5 meters</td>
<td>Tephra. Light gray to white, trough cross-beds, friable. Sample BT-4, (7.76 ± 0.27 Ma) (^1).</td>
</tr>
<tr>
<td>6</td>
<td>1.6 meters</td>
<td>Sandstone. Light brown, tuffaceous.</td>
</tr>
<tr>
<td>7</td>
<td>1.7 meters</td>
<td>Siltstone. Light brown.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>124.7 meters</td>
<td>Total</td>
</tr>
</tbody>
</table>

\(^1\) Ma = million years ago
Undifferentiated Conglomerate Member

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8.</td>
<td>2.6 meters</td>
<td>Conglomerate. Pebble size, subrounded to rounded clasts of limestone quartzite and chert.</td>
</tr>
<tr>
<td>9.</td>
<td>1.0 meter</td>
<td>Tephra. Gray, cross-beds. Sample BT-3, (9.51 ± 0.32 Ma)(^1).</td>
</tr>
<tr>
<td>10.</td>
<td>3.1 meters</td>
<td>Sandstone and siltstone. Light brown.</td>
</tr>
<tr>
<td>11.</td>
<td>28.1 meters</td>
<td>Tephra. Gray to cream color. Ledge former, visible from a distance, forms hoodoos, contains large fiamme pumice, large trough cross-beds. Sample BT-2.</td>
</tr>
<tr>
<td>12.</td>
<td>5.2 meters</td>
<td>Siltstone. Light brown.</td>
</tr>
<tr>
<td>13.</td>
<td>3.7 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>14.</td>
<td>3.5 meters</td>
<td>Sandstone. Light brown, friable with scattered clasts.</td>
</tr>
<tr>
<td>15.</td>
<td>14.1 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>16.</td>
<td>2.1 meters</td>
<td>Tephra. Light gray. Sample BT-1 (11.3± 0.38 Ma)((^1).</td>
</tr>
<tr>
<td>17.</td>
<td>16.2 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>18.</td>
<td>25.6 meters</td>
<td>Sandstone. Gray to cream color.</td>
</tr>
<tr>
<td></td>
<td>229.9 meters</td>
<td>Total</td>
</tr>
</tbody>
</table>

1. Shane, 1994 (pers. comm.).
MULE SHOE DITCH

This section is located on the northwest margin of the Ruby Range approximately 21 km northwest of Dillon. Exposures are measured along intermittent bluffs along Mule Shoe Ditch, east of the Beaverhead River. The section can be reached by driving 20 km northwest from Dillon on state highway 41. Turn east on East Bench Road and drive 3 km to Mule Shoe Ditch Road. The section is exposed on the east side of Mule Shoe Ditch Road for a distance of approximately 1.5 km (southwest to northeast) terminating at the gravel pit. This section includes exposures of the Undifferentiated (Tsu) and Quartzite (Tsq) members of the Sixmile Creek Formation. Quartzite Conglomerate Member contains clasts of pink Swauger quartzite, brown Quadrant quartzite, and black Milligan chert with white quartz-veins. The member also contains vertebrate fossils of Dipoides sp.¹ (Pliocene). The Undifferentiated Conglomerate Member contains clasts of Belt Supergroup rocks and vertebrate fossils of Pliohippus sp.¹ (Clarendonian - Blancan). (NE 1/4, sec. 12, T.5S., R.7W. to NE 1/4, sec. 6, T.5 S., R.6W.).

Sixmile Creek Formation

Quartzite Conglomerate Member

| 1. | 2.4 meters | Sandstone. Light brown, tuffaceous with scattered well rounded quartzite pebbles, including pink Swauger quartzite and black Milligan chert. Top of section. |
| 2. | 14.4 meters | Covered |
| 3. | 2.4 meters | Sandstone. Light brown, tuffaceous, friable. |
| 4. | 12.7 meters | Covered |
| 5. | 31.6 meters | Sandstone. light brown, tuffaceous, friable, thinly to thickly laminated beds. |
| 6. | 3.7 meters | Siltstone. Tan, tuffaceous, friable, thinly laminated beds. |

67.2 meters Total
### Undifferentiated Conglomerate Member

<table>
<thead>
<tr>
<th></th>
<th>Thickness</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>6.5 meters</td>
<td>Tephra. Light gray, friable, coarse tuff. Sample MSD-2.</td>
</tr>
<tr>
<td>8</td>
<td>1.5 meters</td>
<td>Sandstone. Light brown, tuffaceous friable.</td>
</tr>
<tr>
<td>9</td>
<td>3.4 meters</td>
<td>Siltstone. Light brown, tuffaceous, friable, thinly laminated beds.</td>
</tr>
<tr>
<td>10</td>
<td>10.1 meters</td>
<td>Sandstone. Light brown, tuffaceous.</td>
</tr>
<tr>
<td>11</td>
<td>20.6 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>12</td>
<td>1.5 meters</td>
<td>Conglomerate. Pebble size, subrounded to rounded clasts of quartzite, kspar, limestone, chert, red and green argillite in calcareous matrix.</td>
</tr>
<tr>
<td>13</td>
<td>5.7 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>14</td>
<td>11.3 meters</td>
<td>Sandstone. Tan, tuffaceous, friable.</td>
</tr>
<tr>
<td>15</td>
<td>8.9 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>16</td>
<td>17.6 meters</td>
<td>Sandstone with thinly to thickly laminated siltstone interbeds.</td>
</tr>
<tr>
<td>17</td>
<td>10.7 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>18</td>
<td>5.1 meters</td>
<td>Siltstone. Light brown, thinly laminated.</td>
</tr>
<tr>
<td>19</td>
<td>7.9 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>20</td>
<td>10.1 meters</td>
<td>Sandstone. Light brown, tuffaceous, friable.</td>
</tr>
<tr>
<td>21</td>
<td>3.8 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>22</td>
<td>3.4 meters</td>
<td>Tephra. Light gray, cross-bedded. Sample MSD-1.</td>
</tr>
<tr>
<td>23</td>
<td>10.8 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>24</td>
<td>2.2 meters</td>
<td>Siltstone. Light brown with scattered pebbles of limestone, quartzite, gneiss, red and green argillite.</td>
</tr>
<tr>
<td>25</td>
<td>5.5 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>26</td>
<td>0.7 meters</td>
<td>Conglomerate. Clast supported, cobble size, subangular to subrounded clasts of quartzite, limestone, gneiss, red and green argillite in calcareous matrix, imbrication to the south.</td>
</tr>
<tr>
<td>27</td>
<td>1.8 meters</td>
<td>Covered.</td>
</tr>
<tr>
<td>28</td>
<td>4.7 meters</td>
<td>Conglomerate. Clast supported, subangular to subrounded clasts of quartzite, gneiss, red and green argillite. Base of section.</td>
</tr>
</tbody>
</table>

221 meters Total

1. Petkewich, 1972
BILTMORE ROAD SECTION

This section is located about 4 km northwest of the Mule Shoe Ditch section. The section was measured from the south side of Biltmore Road to exposures along bluffs on the north side of Biltmore Road, west of the Beaverhead River. The section can be reached by driving 32 km northeast of Dillon on state highway 41. Turn west on Biltmore Road and drive 3 km west. This section includes exposures of the Passamari Member (Trp) of the Renova Formation and the Undifferentiated Conglomerate Member (Tsu) of the Sixmile Creek Formation. The Passamari Member contains vertebrate fossils of Mesohippus sp.¹ and Leptomeryx sp.¹ (Chadronian - Arikareean). The Undifferentiated Conglomerate Member contains clasts of Belt Supergroup rocks and vertebrate fossils of Pliohippus sp.¹ (Clarendonian - Hemphillian).

(SE 1/4, sec. 3, T.5S., R.7W., to S. 1/2, sec. 26, T.5S., R.7W.)

Sixmile Creek Formation

Undifferentiated Conglomerate Member

1. 5.2 meters Conglomerate. Clast-supported, cobble size, subangular to rounded, clasts of quartzite, limestone, and mudstone, crudely stratified. Top of section.

2. 47.9 meters Covered.

3. 0.3 meters Conglomerate. Same as 1.

4. 2.6 meters Sandstone. Light brown.

5. 1.2 meters Conglomerate. Clast-supported, pebble to cobble size, subangular to rounded, clasts of quartzite, limestone, pegmatite, mudstone, and minor dolomite, imbricated southeast.

6. 0.8 meters Sandstone. Light brown.

7. 1.0 meter Conglomerate. Clast-supported, pebble to cobble size, subangular to subrounded, clasts of quartzite, limestone, mudstone and minor dolomite.

59 meters Total