Cenozoic Sedimentary Evolution of the Helmville Basin, West-Central Montana

Julian Glenn McCune
*The University of Montana*

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Cenozoic Sedimentary Evolution of the Helmville Basin,

West-Central Montana

By

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Thesis

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Abstract

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Cenozoic Sedimentary Evolution of the Helmville Basin, West-Central Montana

Chairperson: Marc S. Hendrix

The Helmville basin is an intermontane topographic depression located ~100 kilometers east of Missoula, Montana. The basin occurs within the Rocky Mountain Fold and Thrust Belt and is immediately north of the Lewis and Clark structural Lineament. The Helmville Basin contains sedimentary and volcanic fill of Paleogene and Neogene age, along with abundant Quaternary sediment. The purpose of this study is to document the geologic evolution of the Helmville basin through a combination of field-based geologic mapping and sedimentologic characterization and to assess the nature of geological resources the basin contains. I also seek to test a rift shoulder tectonic model presented by Janecke (1994) for western Montana and Idaho by reconstructing the paleogeography of the Helmville basin and comparing those results against the model predictions. To accomplish these goals, I constructed a 1:24,000 scale geologic map of the study area, measured a well-exposed section of Paleogene and Neogene sedimentary strata, conducted compositional analysis of Paleogene and Neogene sandstone framework grains and conglomerate clasts, and measured paleocurrent directional indicators.

The western edge of the study area consists mainly of massive undifferentiated andesite and basalt that is Eocene in age. Oligocene sedimentary strata belong to the Cabbage Patch beds of the Renova Formation, which in the study area consists of well sorted sandstone and fossiliferous mudstone interpreted to represent meandering fluvial and paludal (swamp) floodplain environments. Measured paleocurrent indicators within the Cabbage Patch beds suggest that sediment was transported from south to north. Neogene strata consist mainly of massive gravel of the Sixmile Creek Formation, which is composed dominantly of Proterozoic metasedimentary clasts. Paleoflow was from west to east. The deposition of the Sixmile Creek Formation gravel facies appears to have been controlled by a down-to-west normal fault on the east side of the Helmville basin. Erosional excavation of Neogene gravels and older sediments and volcanics beginning in the late Neogene is suggested by the preserved thicknesses and regional distribution of these sediments across the study area. During the Quaternary, a large lobe of ice originating from the Monture Creek drainage blocked the upper Blackfoot River drainage, impounding a proglacial lake in the study area (glacial Lake Blackfoot). A Gilbert-style delta prograded into this glacial lake from Yourname Creek drainage, located on the western edge of the study area.

I infer that the Helmville basin formed as a result of down-dropping along a major southwest-facing normal fault located on the eastern edge of the basin. This fault is mostly obscured by Paleogene gravel but is locally exposed. The presence of aligned tufa mounds within the central part of the basin suggests the presence of at least one additional en echelon fault.
Acknowledgements

First and foremost I would like to thank my chair Dr. Marc Hendrix, my committee members, Dr. Julie Baldwin and Dr. Ulrich Kamp, and The University of Montana for affording me the opportunity to pursue a Master’s degree. Without the support of the citizens of Helmville Montana, in the form of land access, historical data, and overall friendliness this project would not have been possible. Of note, the families of Bignell, Coughlin, Manley, Mannix, Meyer, Ostler, Rohrer, and Weaver were especially helpful. Thanks also are due to Billy Struna at the Helmville Post Office for use of their phone and the Copper Queen Saloon for ice and water. I was granted permission to camp at Brown’s Lake campground by Montana Fish, Wildlife, and Parks. This project was funded in part by grants from the Geological Society of America, the Montana Association of Geographic Information Professionals, the Tobacco Root Geological Society, and the J. David Love field scholarship. The summer field season of 2006 was funded in part by a grant from the EDMAP Component of the U.S. Geological Survey National Cooperative Geologic Mapping Program (Contract Number 06HQAG0080). Finally I would like to thank my family and friends, without whose support none of this would have been possible.
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Introduction

The Helmville basin lies within Powell County, west central Montana, along highways 200 and 141 and approximately 100 kilometers east of Missoula Montana (Fig. 1). This approximately 100 square kilometer study area is bounded on the north by the Blackfoot River, on the west by the Garnet Range and on the east by the Boulder Range. The basin interior is primarily ranch and range land used for hay and cattle production. The only urban center within the study area is the town of Helmville (pop ~100).

The climate of the area is semi-arid; winters are damp and cold while summers are dry with cool nights and warm days. The mean annual precipitation at Helmville for the period of 1984-2007 was 33 cm and the mean annual temperature was 21º C. Vegetation in the Helmville basin is typically xeric (dry) with sage scrub in the valley floor and pine-dominated forests at higher altitudes. This area consists of three distinct land morphologies: flat valley center, gently sloping foot hills, and densely forested highlands.
Geologic Setting

Lewis and Clark Lineament

The Lewis and Clark Lineament (LCL) bounds the southern part of the Helmville basin (Fig. 2). This fault zone trends WNW-ESE and stretches from northwestern Washington southeast as far as Billings, Montana. Wallace and others (1990) proposed that movement on the LCL and associated faults
occurred intermittently from Late Cretaceous to Holocene time with the largest
displacements (23-11 km) offsetting Cretaceous sedimentary strata in a left
lateral sense during the Late Cretaceous and Early Paleocene. During this time,
the LCL in western Montana appeared as a positive flower structure with steep
shear at depth expressed at the surface as outward facing folds and thrusts
(Sears 1998, 2001; White, 2000). These Late Cretaceous and Paleocene
structures are overlain by relatively undeformed Eocene volcanics, suggesting
little substantial post-25 Ma movement and minimal Neogene activity (Sears and
Clemens, 2000; White 2000).

During Paleogene time, displacement along the LCL changed to right
lateral as the regional strain regime changed from compressional to extensional
(Wallace and others, 1990; Doughty and Sheriff, 1992; White, 1993; Yin and
others, 1993). The onset of uplift and exhumation of regional metamorphic core
complexes, widespread volcanism, and delineation of Paleogene depocenters
including the Helmville basin can be attributed to the transition from Cretaceous
left-lateral transpressional stress to Paleogene right-lateral transtensional stress
along the LCL between 59 and 53 Ma (Chadwick, 1985; Fields and others, 1985;

Rocky Mountain Fold and Thrust Belt

A majority of intermontane basins in western Montana were formed as
extensional half-grabens within the Rocky Mountain Fold and Thrust Belt (Sears
and others, 2000; Sears, 2003, see Figure 2). Sears and Fritz (1998) described
three distinct episodes of extensional faulting during Paleogene, middle Neogene, and late Cenozoic time. Many Cenozoic basins in western Montana formed initially during the late Paleogene episode with the extensional collapse of the Cordilleran foreland fold and thrust belt (Constenius, 1996). Extensional faulting largely followed trends established during the Archean (Ruppel, 1982, 1993) with several episodes of reactivation since, including the late Cenozoic activity.

**Oligocene Rifting**

Janecke (1994) suggested that a roughly N-S trending Eocene to Oligocene rift zone stretched from southern Nevada into British Columbia and was located west of the proposed field area (Fig. 3). Janecke (1994) described conglomerates and breccias from the rift zone and interpreted them to be proximal alluvial fan sediments deposited in a series of interconnected grabens and half-grabens. Fine-grained distal alluvial fan sediments are missing from Janecke’s (1994) field study site within the inferred main rift valley, suggesting that the graben system was drained by a through flowing, high gradient stream network that transported fine-grained sediment out of the main rift valley.

According to Janecke’s (1994) model, the regional tilt of the footwall block rift shoulders away from the main rift valley may have effectively prohibited the widespread introduction of fine-grained sediment into the main rift valley, instead directing it off to the east and west. In this model, one such deposit is the
Figure 3 Oligocene rifting. Possible relationship between Renova basin sediments and Janecke's (1994) model. Rectangle denotes location of the Helmville basin on the eastern flank of Renova basin. LCL-Lewis and Clark lineament, ESRP-Eastern snake river plain, RMFTB-Rocky mountain fold and thrust belt, RB-Renova Basin, HB-Helmville Basin.
Cenozoic Renova basin sediments of western Montana. The Helmville basin is located on the northern edge of Janecke’s proposed Renova Basin (Fig. 3).

**Hall Basin**

Portner (2005) documented pebble imbrication in coarse Renova age gravels from Hall basin, located immediately southwest of the Helmville basin. Imbrication directions and other paleocurrent indicators measured by Portner (2005) suggest at least two major reorganizations in basin facing directions occurred within the Hall basin. Cross-bedded sandstone deposits within the lower Renova Formation of the Hall basin are northwest directed. In contrast, pebble imbrications measured just above a regional mid-Neogene locally angular unconformity indicated a flow reversal, with dispersal to the east. By late Neogene time, flow had been restored to the northwest as the modern Clark Fork River system apparently began to take shape. Provenance data from sandstones and conglomerates in the Hall basin also are consistent with the two major flow reversals suggested by the paleocurrent indicator orientations (Portner, 2005). Importantly, the integrated basin evolution history suggested by the new data from Portner (2005) does not appear to be consistent with the paleogeographic model proposed by Janecke (1994) for this part of the Oligocene rift system.
Objectives

In order to understand the Cenozoic evolution of the Helmville Basin I constructed a geologic map at 1:24,000 scale (Plate 1) with accompanying cross-sections (Plate 2) and paleogeographic models. I measured all distinct stratigraphic sections (Plate 3) and available paleocurrent indicators, and I performed compositional analyses on sandstones and conglomerates to better constrain provenance relations. These data sets will also help qualify the nature and availability of economically viable geologic resources within the Helmville basin, including potential aquifers and gravel sources.

Through my mapping and analysis of the sedimentary and volcanic fill history within the Helmville basin, I present a test of the paleogeographic model proposed by Janecke (1994) for the study area. If Janecke’s model is correct, my work should reveal an overall eastward-fining series of sedimentary strata and evidence of transport to the east. In addition to testing the basin evolution model proposed by Janecke, I examined the nature and composition of Cenozoic strata from the Helmville basin for direct comparison with the conclusions reached by Portner (2005), who studied age-equivalent strata in the Hall basin to the south. Specifically, I seek to characterize the sedimentary transition associated with the Middle Neogene unconformity in the Helmville basin and consider this in the context of the region’s changing paleogeography as constrained from other localities.
Previous Work

Paleogene sediments in western Montana were first described by Earl Douglass in 1903. The first geologic map of western Montana was constructed in 1955 by Ross and others, with subsequent mapping by Wallace (1987), Lewis (1998) and Vuke and others (2007) at 1:250,000 scale. Konizeski (1959) provided a brief description of the Helmville basin; however, the most relevant geologic, stratigraphic, and paleontologic descriptions in the vicinity of the Helmville basin were reported by Rasmussen (1969, 1977) with detailed floral and faunal descriptions by Person (1972), Pierce and Rasmussen (1992), Pierce (1992, 1993), Henrici (1994), and Portner (2005).

Volcanic deposits of the Garnet Range were explained by Carter (1982) with age dates from Williams and Harakal (1976). The Montana Bureau of Mines and Geology published a guide book (Rasmussen and Fields, 1980; Miller, 1980) that described structure and stratigraphy of the Helmville basin. Kuenzi and Fields (1971) first described the stratigraphy of the area, and this initial work was followed by more refined stratigraphic descriptions by Fields and others (1985), Hanneman and Wideman (1991), Rasmussen and Prothero (2003), and Rasmussen (2003). Gwinn (1965) and Portner (2005) conducted detailed geologic descriptions in similar Cenozoic basins to the east of the field area.
Methods

Field Techniques

Geologic mapping was conducted in the field on 1:15,000 USGS topographic maps printed with National Geographic Topographic software. A Brunton Pocket Transit compass was used to measure bedding attitudes and paleocurrent indicator directions, and a Garmin Etrex Vista GPS unit was used to determine sample locations. Stratigraphic sections were measured with a 1.5 meter Jacobs staff with decimeter divisions and Brunton Pocket Transit compass. Representative samples of each stratigraphic unit were collected from across the map area.

Laboratory Techniques

The finished geologic field map was digitized at 1:24,000 using ESRI’s ArcGIS 9.0, consistent with the database format outlined by the Montana Bureau of Mines and Geology in 2007. Cross-sections and other figures were constructed using Adobe Illustrator CS 11.0. Descriptions of each stratigraphic unit were made by supplementing field observations with descriptions of smear slides of fine-grained units. Paleocurrent indicator measurements were plotted on rose diagrams using Stereonet (v. 6.3.3), a program developed by Rick Allmendinger (2006) and following the techniques of DeCelles and others (1983). In order to provide a basis for the interpretation of provenance, 16 thin-section samples were point-counted using a James Smith point counter (model # C
4251) on a Leitz Orthoplan petrographic microscope (model # 792392). Results were plotted on ternary diagrams using Triplot software (Thompson, 2005). Plots were interpreted using the Gazzi-Dickenson point count method outlined by Dickenson and Suczek (1979) and Ingersoll and others (1985). Conglomerate provenance was determined by sampling 56 locations across the map area and identifying over 5000 gravel clasts as metasedimentary, volcanic, plutonic, or sedimentary, following the procedures outlined by Miall (2000).

**Sedimentology**

Intermontane basins of western Montana record a rich history of Cenozoic sedimentation in the region (Fig. 4). These deposits are described and classified by Kuenzi and Fields (1971) with further refinement by Fields and others (1985), Hanneman and Wideman (1991), Rasmussen and Prothero (2003), and Rasmussen (2003). Paleogene strata are divided into Eocene volcanic units, Oligocene fine-grained strata deposited in low-energy flood plain and pond environments (Renova Formation), and Neogene deposits characterized by coarse-grained strata which accumulated in relatively high-energy ephemeral and perennial channel environments on alluvial fan surfaces (Sixmile Creek Formation; Fields and others, 1985). Recent work in the Helmville basin by Rasmussen (1969, 1977) and in the neighboring Hall basin (Portner, 2005) indicated the presence of similar fluvial sandstones, paludal mudstones, and alluvial gravels consistent with the descriptions by Kuenzi and Fields (1971). Paleogene and Neogene deposits described herein are consistent with
<table>
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<td>37.7</td>
<td>Duchesnean</td>
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Figure 4 Stratigraphic correlation chart.
correlations made by Fields and others (1985), Rasmussen and Prothero (2003), and Rasmussen (2003) for informal units within the Renova and Sixmile Creek Formations (Figure 4).

Exposure in the Helmville basin is limited and absolute thickness of map units are by necessity estimated. Relative thickness, lithology, and basin stratigraphy of deposits revealed by geologic mapping are illustrated in the composite stratigraphic chart presented in Figure 5. All map units are described and interpreted in detail below.

<table>
<thead>
<tr>
<th>Map Units</th>
<th>Stratigraphic Name</th>
<th>Thickness</th>
<th>Lithology</th>
<th>Age series</th>
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<tr>
<td>Glacial Lacustrine</td>
<td>——</td>
<td>5-10 meters</td>
<td>Massive interbedded clay and mudstone</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>Six Mile Fmtn</td>
<td>Sixmile Fmtn</td>
<td>~45 meters</td>
<td>Poorly consolidated sand and gravel</td>
<td>Lower Miocene</td>
</tr>
<tr>
<td>Cabbage Patch Beds</td>
<td>Renova Fmtn</td>
<td>~200 meters</td>
<td>Bedded fluvial mudstones and pebbly sandstones</td>
<td>Oligocene</td>
</tr>
<tr>
<td>Andesite and Basalt</td>
<td>Garnet Range Volcanics</td>
<td>Unknown</td>
<td>Fractured vesicular basalt</td>
<td>Eocene</td>
</tr>
<tr>
<td>Belt (Undifferentiated)</td>
<td>——</td>
<td>Unknown</td>
<td>Meta-sedimentary rocks</td>
<td>Proterozoic</td>
</tr>
</tbody>
</table>

Figure 5 Composite stratigraphic Chart for the Helmville Basin.

Middle Proterozoic rocks of the Belt Supergroup to have been deposited in an intracratonic basin flanked by alluvial aprons that terminated in a landlocked sea. Belt Supergroup rocks in the map area consist of a complex assemblage of sedimentary rock types that include carbonates, siliciclastic mudstones, sandstones, and conglomerates, all of which are slightly metamorphosed.
Listed in order of decreasing age, the Belt Supergroup units exposed or inferred to be present in the Helmville basin include red siltite of the Spokane Formation (Ys), grey-green dolomitic argillite and siltite of the Empire Formation (Ye), grey dolomite of the Middle Belt Carbonate (Yc) (re-named Piegan Formation by Winston, 2007), pink to tan quartzite of the Snowslip Formation (Ysn), red dolomitic quartzite of the Shepard Formation (Ysh), red quartzite, argillite, and siltite of the Mount Shields Formation (Yms), and red/pink to tan quartzite of the Bonner Quartzite (Ybo). Belt units in the Helmville basin define the faulted eastern margin of the map area as a major change in slope and occur as a newly mapped (this study) isolated highland surrounded by Eocene volcanics in the western part of the map area (see Plate 1). Detailed descriptions of these units within the map area are presented in Appendix A.

*Paleogene and Neogene Rocks*

**Tab Andesite and Basalt (Eocene)**

Massive undifferentiated andesite and olivine-bearing basalt form a series of highlands in the western part of the map area (Fig. 6). This stratigraphic unit is highly fractured and readily forms cliffs with local crude columnar jointing (Fig. 6a). In hand specimen, the rock is locally vesicular and subporphyritic with a speckled appearance and subordinate plagioclase phenocrysts up to 5 mm in places. Color ranges from dark grey/black to brick red where the rock is notably porous in hand-specimen. In thin section, the rock is basaltic with intergranular texture and abundant euhedral olivine phenocrysts (Fig. 6b).
Williams and Harakal (1976) and Carter (1982) acquired K-Ar age dates of 44.9 +/- 2 Ma on the western flank of Garnet Range near Bearmouth Montana (~70 km west) indicating the presence of a middle Eocene eruptive sequence. This timing correlates with the Challis, Lowland Creek, and Absaroka volcanic and plutonic episodes (Armstrong, 1974; Chadwick, 1985). The Garnet Range volcanics were primarily fissure eruptions that occurred within a large single Eocene eruptive episode (Carter, 1982).

More than 180 meters of rhyolite, latite, andesite, and olivine basalt were emplaced as flows in the Bearmouth area (Carter 1982), northwest Hall basin (Portner, 2005), and the western Helmville basin. Because its base is not exposed, the exact thickness of olivine basalt cannot be determined for the Helmville basin; however, Carter (1982) described the olivine basalt of the Bearmouth area as no thicker than 75 meters.
**Tvd Volcanic Debris Flow (Eocene)**

Monomict debris flow deposits are exposed in a road cut in the southeast corner of the map area. This unit consists of stratified volcanic clasts in a mud matrix and thinly bedded grey ashy mudstone (Fig. 7a). Volcanic clasts are well rounded and range greater than 20 centimeters in size. Clasts are locally matrix-supported with the largest clasts occurring at the top of the unit. The unit is capped by massive Tab basalt and is approximately 20 meters thick.

The occurrence of large (20 cm and larger) isolated clasts at the top of the deposit suggests rafting of clasts in a plug flow. Thinly bedded ashy mudstones interbedded with the massive monomict debris flows imply periods of channelized fluvial deposition between major debris flows. This debris flow deposit has abundant relict basalt and andesite clasts (Fig. 7b) that are baked into the deposit, leaving only a color outline. These clasts are highly welded

![Figure 7 Volcanic debris flow. a. Outcrop with person for scale. b. Relict clasts (circles), bottom left clast is brittle from heat spalling and upper right clast is welded into the deposit.](image)
(break across clast edges), brittle, and show evidence of heat spalling.
Stevenson and others (1993) observed similar relict clasts in New Zealand on Mayor Island and concluded they are a product of heat during deposition. Along with a thick basalt cap, the possibility of hot emplacement observed in this unit implies syn-deposition with Eocene andesite and basalt.

**Tcp Cabbage Patch Beds (Oligocene)**

This informal unit of the Renova Formation (Fields and others, 1985) consists of tabular meter-scale beds of pebbly sandstone and interstratified mudstone. In general, this unit is poorly exposed in the study area with the primary exposure (Fig. 8a) being along a stream channel southwest of Helmville. Thin-section observations (Fig. 8b) and point count analysis (described below) indicate that the sandstone is a feldspathic (arkose) arenite.

Sandstone of the Cabbage Patch beds is very coarse and very well cemented; clasts are poorly sorted and angular with a maximum clast size of 1 centimeter. Thin-section analysis (Fig. 8b) reveals that clast types include rounded mono and polycrystalline quartz, angular potassium feldspar and plagioclase, with lesser amounts of plutonic, volcanic, sedimentary, and metamorphic rock fragments. Cements include clay (sericite), chalcedony, and calcite suggesting multiple episodes of diagenesis. Potassium feldspar altering to clay, iron oxide coatings, and in situ fracturing all support a complex diagenetic history that likely includes pedogenesis.
Mudstone interpreted to have been deposited in a paludal environment is interbedded with Cabbage Patch sandstone beds and varies in color from olive green to tan to grey, with some calcium carbonate nodules and local root traces. The presence of calcium carbonate mud is commonly associated with increased quantities of sponge spicules, shell fragments, and lacustrine gastropod fossils.

A two hundred meter-thick section of the Cabbage Patch beds was measured in the Helmville basin and is graphically represented in Plate 3. Paleocurrent indicator directions (see below) consist mainly of asymmetric ripple foresets that suggest south to north paleoflow. Sandstone bodies are locally lenticular; both normally and inversely graded in places with silica replacing wood fragments, and contain ripple forsets and clay rip-up clasts. Mudstones locally contain minor calcium carbonate, lacustrine gastropod fossils (Gastropoda), and

Figure 8 Cabbage Patch sandstone. a. Outcrop view with decimeter Jacob staff for scale. b. Thinsection view in crossed polarized light at 10X magnification.
sponge spicules (Demospongea). A complete list of fossils recorded in the Arikareean Cabbage Patch Beds and references can be found in Appendix B.

The mud-dominated nature of the Cabbage Patch beds, along with the observed sedimentary structures and lithologies, suggests a mud-dominated meandering fluvial system within a large swampy floodplain containing abundant standing water. Paleocene and Eocene strata from the Powder River basin in Wyoming exhibit similar sedimentary characteristics and also are interpreted to have been deposited in a similar, mud-rich meandering fluvial environment (Ethridge, 1981). A modern analog to the ancient Blackfoot drainage can be found in the River Dane, England (Hooke, 1986), in which a large swampy floodplain with a pebbly streambed exits today.

**Tft** Tufa (Oligocene?)

Approximately eight sub-aligned concentrically-layered mounds of tufa are located in the southeast corner of map area (Fig. 9). There, tufa mounds form a distinct linear hill surrounded by Eocene andesite and basalt. Although the exact age of the tufa is unknown, map relations suggest early Oligocene deposition. The area in the immediate vicinity of the tufa mounds is littered with abundant permineralized wood fragments, consistent with the interpretation of mineralizing hydrothermal fluids. I interpret the sub-aligned tufa mounds to reflect the presence of a fault situated en echelon to the major normal fault that downdrops the east side of the Helmville basin (see geologic map Plate 1).
Tsm Sixmile Creek Formation (Miocene)

In the study area the Sixmile Creek Formation consists of poorly consolidated gravel and sand exposed on high terraces and along valley slopes. This deposit drapes the underlying geology as a thin veneer and consists of framework-supported gravel with angular sand matrix consistent with alluvial fan deposition (fanglomerate). Individual gravel clasts measure up to 1 meter in diameter and are composed of metasedimentary (Proterozoic) and volcanic (Eocene) lithologies with minor percentages of sedimentary and plutonic rocks. Pebble imbrication (discussed below) in places suggests west to east paleoflow directions.
The thickness of this deposit varies throughout the map area and is estimated to be 30 to 45 meters thick with greater accumulations in the east part of the map area judging from exposure. Other Paleogene basins in northwest Montana (e.g., Flint Creek and Deer Lodge basins) have thicker packages of Sixmile Creek gravel – locally up to 425 meters (Rasmussen, 2003, Portner, 2005). Approximately four producing gravel pits are located in strata belonging to the Sixmile Creek Formation within the map area. Map relations and provenance analysis suggest greater accumulation of Sixmile Creek gravel on the eastern side of the Helmville basin (see provenance analysis below and Plate 2). Existing gravel pits located primarily in the eastern portion of map area confirm this interpretation.

**Tbc** Barnes Creek Beds (Miocene)

This informal member of Sixmile Creek Formation (Fields and others, 1985) consists of finely bedded sandstone, sandy mudstone, coarse sand, and gravel of variable thickness. Local sedimentary structures include ripple foresets in sandstone and pebble imbrication in gravel. The unit is unconformably overlain by Sixmile Creek gravel and is poorly exposed in map area. Where present, west to east paleocurrent directions are suggested in the limited exposures.

Approximately 20 meters of this unit are exposed in road cuts along Montana highway 141 (Fig. 10). Stratigraphic measurements (see plate 3) reveal a sandy fluvial system with intermittent muddy overbank deposits. The Barnes
Creek Beds in the vicinity of the Helmville basin are reported to contain vertebrate and plant fossils (Person, 1972; Rasmussen, 1969, 1977; Pierce and Rasmussen, 1992; Pierce, 1992, 1993; Henrici, 1994; Portner 2005), however no fossils were found during this investigation. For a list of reported fossils for the Barstovian-Clarendonian Barnes Creek Beds see Appendix C.

**Quaternary Rocks**

**Qgl** Glacial Lacustrine (Pleistocene)

Glacial lacustrine mudstone deposits 5 to 10 meters thick are exposed along modern stream channels in the northeast corner of map area, particularly...
along the Blackfoot River (Fig. 11). There, the unit consists of decimeter scale interbedded clay and silt with local dropstones ranging in size from sub-millimeter to 20 centimeters. Beds exhibit soft sediment deformation in places, mainly consisting of millimeter- to decimeter-scale folds. Mudstone is locally fissile and ranges in color from tan to red. The sedimentology of this stratigraphic unit is consistent with massive unstructured parts of the Sanpoil River valley glacial deposits in Washington State (Atwater, 1986) and the Plio-Pleistocene lacustrine deposits of Glacial Lake Idaho (Miller and Smith, 1965).

Figure 11 Glacio-lacustrine deposits exposed along the Blackfoot River.
**Qd** Glacial Deltaic (Pleistocene)

A poorly consolidated Gilbert-style delta deposit is exposed in a gravel pit in the northwest corner of map area (Fig. 12). There, this unit includes approximately 5 meters of coarsening upward sandy gravel with abundant northeast-dipping trough cross-beds and local symmetrical ripples. These deposits were previously mapped as Paleogene sedimentary rocks by Wallace (1987). This unit likely formed on the margin of a glacial lake (glacial Lake Blackfoot, Qgl) at the mouth of northeast trending Yourname Creek drainage.

![Figure 12 Glacial deltaic deposit. A. Map location, circle denotes location in map area. B. Outcrop exposure in gravel pit.](image)

**Qal** Alluvium (Holocene)

Semi-consolidated to unconsolidated fluvial and overbank deposits approximately 5 meters thick are exposed along modern stream channels (Fig. 13). In the study area this unit consists of gravel and sand with local mud-dominated floodplain deposits. Gravel is well rounded and poorly sorted with local boulder-sized clasts. Mud deposits are very fine silt and sand light brown in
color. No sedimentary structures were observed. Anthropogenic deposits related to local agricultural activities are included in this unit.

Provenance and Paleocurrent Analysis

In order to better understand the Cenozoic paleogeographic evolution of the Helmville basin and further test the geologic model proposed by Janecke (1994), paleocurrent indicators were measured and provenance analyses were performed in Paleogene and Neogene rocks mapped as Renova and Sixmile Creek Formations in the study area (Fields and others, 1985). Analysis of provenance is based on point counts of sandstone samples from the Cabbage Patch Beds, using the Gazzi-Dickenson point count method (Dickenson and Suczek, 1979, Ingersoll and others, 1985), and clast counts of gravel in the Sixmile Creek Formation, using the approach outlined in Miall (2000). Paleocurrent analysis is based on orientation measurements of ripple foreset planes in the Cabbage Patch Beds and oblate imbricated pebble and cobble clasts in the Sixmile gravel.

Figure 13. Quaternary alluvium deposit.
Provenance

Cabbage Patch Beds

Sixteen sandstone samples were collected through the measured section of Cabbage Patch Beds (Tcp) at approximately 10 meter intervals. A standard thin-section was made from each sample, and half of each thin-section was stained with sodium cobaltinitrate to facilitate identification of potassium feldspars. Approximately 500 individual counts were made per thin-section. Specific framework grain constituents that were recorded included monocrystalline quartz (Qm); polycrystalline quartz (Qp), chert (Cht), potassium feldspar (K), plagioclase (P), volcanic lithics (Lv), sedimentary lithics (Ls), and metamorphic lithics (Lm). Results were plotted on ternary diagrams (Fig. 14) following Dickenson and Suczek (1979) and Ingersoll and others (1985).

Figure 14a displays likely source rocks via total quartz, total feldspar, and total lithic fragments. This plot shows that sandstones in the Helmville basin are compositionally immature and suggestive of derivation from multiple source terrains. The data plotted in Figures 14a and 14b are similar and consistent with the interpretation that feldspar in the Cabbage Patch Beds is derived mainly from Eocene volcanic rocks to the west of the map area whereas quartz populations are recycled from the Proterozoic Belt Supergroup rocks to the east and south of the map area. This interpretation is supported by observations of rounded quartz grains and angular feldspar grains in each of the thin-sections (see Figure 8b).

Figure 14c shows normalized populations of polycrystalline quartz, lithic volcanic and lithic sedimentary grains. This plot shows an apparent bimodal
distribution and suggests the possibility that the main source of detrital grains alternated through time between volcanic-dominated sources and Belt Supergroup-dominated sources. Together, the three ternary plots suggest that the main source area for the Renova sandstones was south and west of the Helmville basin, where abundant volcanic and Proterozoic metasedimentary rocks exist. In contrast, the area north of the study area lacks widespread
exposures of volcanic rocks and instead contains mostly fine-grained Cambrian siliciclastics and carbonates.

**Sixmile Formation**

Fifty-six samples of gravel and gravel chips of the Sixmile Formation (Tsm) were collected across the field area. Each sample contained approximately 100 clasts, and nearly 5500 clasts were identified and cataloged as volcanic, plutonic, sedimentary, and metasedimentary (Belt Supergroup) rocks. Metasedimentary clasts were sub-divided as quartzite (red, white, and green), argillite, and carbonate to better differentiate sources presumed to be associated with the Proterozoic Belt Supergroup (Fig. 15). Sample locations and details of clast count analysis can be found in Appendices D and E.

In general, Sixmile gravel deposits in the western portion of the Helmville basin (A-C) have a higher percentage of volcanic clasts, whereas deposits in the south and east of the map area (D-F) contain a higher percentage of metasedimentary rocks. Sixmile gravel compositions from the eastern margin of the basin (E and F) suggest a different gravel source than that for the western and southern margins of the basin. Specifically, location E is dominated by metasedimentary carbonate clasts inferred to be derived from the Middle Belt Carbonate (Yc, renamed Piegan Formation by Winston, 2007) which is widespread along the eastern margin of the field area. In contrast, gravels from regions A, B, C, D, and F likely were derived from the western and southern
Figure 15  Sixmile Creek Formation gravel clast count analysis. Color dots show corresponding pie chart. Arrows show general paleoflow directions revealed from clast count analysis.
margins of the Helmville basin because they contain an abundance of volcanic clasts.

These provenance observations suggest deposition of Sixmile gravel in the Helmville basin was controlled by activation or reactivation of the basin bounding normal fault on the eastern margin of the map area, with large hanging wall alluvial fan deposits in the west (A-C), south (D), and northeast (F) and small footwall alluvial fan deposits exposed in the southeast (E) of the map area. This fault controlled distribution of alluvial fan morphology is analogous to that which occurs today in southern Death Valley along the Panamint Range where large hanging wall-derived fans in the west interfinger with much smaller footwall-derived fans in the east (Denny, 1965).

Paleocurrent Indicator Analysis

Measured unidirectional paleoflow indicators within the Helmville basin include ripple foresets in the Oligocene Cabbage Patch Beds and pebble imbrications in the Miocene Sixmile gravel. These measurements are plotted on rose diagrams (Fig. 16) using the methodology described in DeCelles and others (1983). Twenty-three strike and dip measurements of sandstone ripple forsets were recorded from the Cabbage Patch Beds (200 meters). Paleoflow directions from south to north (Fig. 16a) are consistent with the conclusions drawn from provenance analysis of derivation from the south for Renova-equivalent sandstones in the Helmville basin.
Twenty-four strike and dip measurements of imbricated oblate pebbles were recorded at one locality in a small gravel pit on the eastern side of the Helmville basin. These measurements show west to east paleoflow directions (Fig. 16b). Although the geomorphology and map relations of Sixmile Creek deposits in the eastern Helmville basin suggest alluvial fan style depositional
features originating from the east (see Fig. 16 and Plate 1), both provenance analysis and paleocurrent directions suggest deposition from west to east.

**Paleography**

In order to construct paleogeographic models for Cenozoic evolution of the Helmville basin, I integrated results from map relations, stratigraphic unit descriptions and interpretations, provenance analysis, and paleocurrent indicator directional measurements. These paleogeographic models, described below for Eocene through Pleistocene Epochs, illustrate depositional style and regional paleoenvironment.

**Eocene**

Emplacement of Garnet Range volcanic rocks (Tab) that form the western highlands of the Helmville basin occurred in early Eocene time (Fig. 17). Little is preserved beyond basalt and volcanic debris flow deposits; therefore, little information about the basin interior depositional environment and sedimentology is known.

The olivine basalt thickens west of the map area into the Garnet Range and is likely a single flow unit originating in the west. This unit is relatively homogenous in the map area and differs only in the degree of weathering and vesiculation. Basalt thins to the east suggesting the vent system lies west of the map area as concluded by Carter (1977).
Faulted Proterozoic Belt Supergroup rocks form the eastern highlands of the map area as well as a small buried hill exposure within the Eocene andesite and basalt on the western side of the map area. This exposure indicates that within the Helmville basin the Eocene volcanics were deposited immediately on top of rocks belonging to the Belt Supergroup. Although map relations and field investigations suggest that the eastern margin of the Helmville basin is normally faulted, forming a down to the west half-graben, it is uncertain whether this fault was active during Eocene time.

**Oligocene**

During Oligocene time sedimentation in the study area was dominated by deposition of the Cabbage Patch Beds (Tcp). This unit consists of pebbly sandstone interstratified with fine-grained mud and is interpreted to have been deposited in a meandering fluvial system with a large paludal flood plain.
Paleocurrent indicators show south to north paleoflow directions. Results from provenance analysis are consistent with a likely source area to the south and west of the map area that supplied feldspars and volcanic rock fragments from Eocene volcanics along with quartz and sedimentary rock fragments from Proterozoic metasedimentary rocks of the Belt Supergroup.

Oligocene deposits also contain locally abundant wood fragments, sponge spicules, and gastropod fossils, suggesting a lush wet environment (see fossil list Appendix B). This meandering fluvial system is interpreted to be analogous to Eocene mud-dominated meandering fluvial deposits documented by Ethridge (1981) in the Powder River basin in Wyoming as well as the modern fluvial environment documented by Hooke (1986) in the River Dane in England.

During Oligocene time, major initial incision of andesite and basalt from the southwest likely occurred, contributing to the abundance of volcanic rock.
fragments and feldspars observed in sandstones of this age. It is unclear, however, whether movement on the major basin bounding fault to the east occurred at this time.

Miocene

Miocene strata in the study area consist mainly of alluvial fan sediments composed of the Sixmile Creek Formation (Tsm) gravel and the Barnes Creek Beds (Tbc) fluvial deposits (Fig. 19). Miocene strata in the study area were deposited in a half-graben controlled by the down-to-west basin-bounding normal fault. Provenance and paleocurrent relations suggest that west-derived hangingwall fans were substantially larger than east-derived fans sourced from the footwall and that the basin bounding normal fault controlled the deposition style of the Sixmile Creek gravel. Therefore, I infer that the basin-bounding
normal fault must have been active at least by the time these gravels were deposited. It is possible that the fault formed initially during Neogene time.

**Pliocene**

Starting possibly as early as Late Miocene time and continuing through the Pliocene, the Helmville basin underwent a phase of erosional excavation (Fig. 20). This erosion was probably facilitated by residual movement of the normal fault on the eastern margin of the map area and may represent a distal effect of the evolving Yellowstone Hotspot. This phase of erosion excavated and incised Miocene alluvial fans (Sixmile Formation) and underlying deposits. Based on the lack of Pliocene deposits in the map area, I infer that through-flowing streams accommodated the removal of sediment from the study area during this time period.

![Figure 20 Pliocene paleogeography in the Helmville basin.](image-url)
Pleistocene

During the Pleistocene, a large lobe of ice from the Monture Creek drainage northwest of the map area blocked the Blackfoot River in the vicinity of Russell Gates, inundating much of the Helmville basin (Fig. 21). Abundant glacial lacustrine (Qgl) sediment with dropstones was deposited in the glacial lake; these sediments include the exposures along the Blackfoot River and the gilbert style deltaic deposit at the mouth of Yourname Creek (Qgd) that had previously been mapped as sedimentary rocks of Paleogene age.

Glacial Lake Blackfoot likely was contemporaneous with glacial Lake Missoula but was not physically connected to it, because the elevation of the Helmville basin is ~450 meters higher than the known maximum elevation of the surface of glacial Lake Missoula. No fossils were observed within glacial lake sediments in the map area, although Pleistocene fossil fish have been reported from similar deposits in Glacial Lake Idaho by Miller and Smith (1965).

Figure 21 Pleistocene paleogeography in the Helmville basin.
Geologic Resources

The Helmville basin is undergoing a rapid phase of human development. This investigation of the distribution and character of basin fill will provide community planners with important information regarding the location of economically-valuable geological resources, such as gravel deposits, as well as providing important information regarding the distribution of potential aquifer facies. Potential aquifer deposits within the Helmville basin include basalt of the Garnet Range basalt and sandstone of the Cabbage Patch beds; gravel sources can be found in the Sixmile Creek formation deposits.

The Columbia River basalt (Steele, 1988) in Washington State and the Fallon basalt of Nevada (Maurer, 2001) are two examples of highly fractured basalt aquifers. In order for basalt to act as an efficient aquifer, connectivity between networks of fractures and flow features (gas vesicles, clinker zones) must be established (Fetter 2001). Although highly fractured, the limited thickness and the lack of continuous vesicular zones of this unit suggest that the Garnet Range Eocene basalt is not a viable aquifer.

Two examples of producing sandstone aquifers in the region are the Kootenai Formation in Montana and the Fox Hills Sandstone in Wyoming (Henderson, 1985). These sandstones are thick, porous, and have recharge areas on the order of hundreds of square miles. Porosity of the Cabbage Patch Beds sandstone measured in this study range from 0% in the highly cemented areas up to ~15% in extremely coarse areas. The mainly tabular arrangement of
beds alternating between mudstone (aquclude) and sandstone (aquifer) and
dipping at 15° is a typical geometry for a producing aquifer (Fetter, 2001).
However, the abundance of feldspars altering to clay (sericite) and clay-lined
pores, along with the relatively thin nature of the unit and a small available
recharge area of the Cabbage Patch beds within the Helmville basin are factors
that inhibit the this deposit as a valuable source of economic quantities of water.

The Helmville basin has abundant gravel deposits in the Sixmile Creek
Formation (Tsm). Many existing gravel pits in the map area occur in its eastern
part, on east facing slopes, consistent with cross sections constructed across the
map area (Plate 2) and based on field observations that suggest larger
accumulations of Sixmile Creek Formation gravel on east facing slopes.

Conclusions

Provenance results from coarse grained Oligocene sandstone of the
Cabbage Patch Beds within the Helmville basin suggest derivation of
sedimentary detritus from southwest of the map area with minor contributions
from the east. Paleocurrent analyses of ripple foreset orientations in these
sandstones are consistent with this interpretation, with paleoflow directions from
south to north. These results are inconsistent with but not excluded by Janecke's
(1994) model which suggests that the rocks of the Renova Formation were
deposited on an east-tilted rift shoulder (Fig. 3).

Analysis of clast count data from Miocene Sixmile Creek Formation
gravels suggests an alluvial fan system controlled by the major basin bounding
fault on the eastern edge of the map area. Provenance of these deposits suggest that Sixmile Formation deposits in the northeastern, southern, and southwestern parts of the study area originated from the west southwest of the map area, while deposits in the southeast came from the east of the map area. I infer that Sixmile Creek Formation deposits across most of the map area were deposited in large hanging wall alluvial fans, whereas those on the eastern part of the map area were deposited in small foot wall alluvial fans. Paleocurrent analyses of pebble imbrication from within this unit confirm general paleoflow from west to east.

Results of provenance and paleocurrent analyses in the Helmville basin compare well with Portner's (2005) findings. Deposits in the Helmville basin show at least two major changes in basin facing directions from northward-tilting in the Oligocene to eastward-tilting in the Miocene and most recently to the northwest-flowing Blackfoot River drainage probably beginning in the Pliocene or late Miocene.

Paleogeographic models derived from multiple independent data sets collected within the Helmville basin suggest major changes in depositional environment, basin orientation, and tectonic activity from Eocene to present. A major basin bounding normal fault on the eastern side of the map area has likely been active since Late Neogene time based upon the distribution of Sixmile Formation gravel and major incision and excavation of that gravel. According to Sears (1989) the last major deformation of the Lewis and Clark Lineament occurred ~ 25 Ma ago, consistent with this conclusion. One or more synthetic
faults are located in the southwest of the field area. Timing of activity on these faults appears to be Oligocene based on map relations, suggesting that movement may have been related to the youngest episode of offset on the Lewis and Clark lineament.
Future Work

1) Additional detailed geologic mapping of Cenozoic sedimentary deposits of west-central Montana will assist in correlating findings from this study, Portner’s (2005) work in Flint Creek basin, and others (see Rasmussen and Prothero, 2003) across west central Montana. Likely proximal basins for further investigation include the Clearwater, Lincoln, Potomac, Douglass Creek, Avon/Nevada Creek, and Deer Lodge basins.

2) Detailed descriptions and mapping of glacial deposits and features in the areas surrounding the Helmville basin will refine the extent and timing of glacial Lake Blackfoot. This study should concentrate on glacial deposits, the existence of shorelines, glacial history of the Monture Creek drainage, as well as any outwash features in the vicinity of Russell Gates.

3) In order to continue testing Janecke’s (1994) model, I propose further point count provenance analysis on Cabbage Patch Beds sandstone from other west-central Montana Cenozoic basins (see Rasmussen and Prothero (2003). Clast provenance analyses of Sixmile Creek Formation gravel in above mentioned Cenozoic basins of west-central Montana will provide another basis for comparison with findings in this study.
5) A new radiometric date of olivine bearing basalt from the eastern Garnet Range will provide an important comparison with dates from Williams and Harakal (1976) and Carter (1982) of 44.9 +/- 2 MA K-Ar on the western Garnet Range.
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APPENDIX A

Descriptions of Proterozoic Belt Supergroup rocks in the Helmville basin from field observations.

Ybo  Bonner Quartzite
Poorly exposed red/pink to tan, tabular quartzite located on the southwestern margin of map area. Beds are mm to cm thick and contain mud chips, matrix-supported pebbles, symmetrical ripples and sub-millimeter laminations. 210 meters exposed in map area.

Yms  Mount Shields Formation
Reddish quartzite and subordinate argillite and siltite (Lewis, 1998). Unit is inferred in subsurface on cross section (Plate 2).

Ysh  Shepard Formation
Cm- to dm-scale beds of red dolomitic tabular quartzite, siltite, and argillite beds. Abundant in southeast corner of map area. Argillite exhibits mudchips and microlaminations. Approximately 100 meters exposed in map area.

Ysn  Snowslip Formation
Coarse pink to tan quartzite exposed in southeast corner of map area. Tabular mm- to cm-scale beds contain well rounded quartz grains without apparent sedimentary structures. Deposit is strongly brecciated near fault contact with Yc in southeastern part of map area. 30 meters exposed in map area.

Yc  Middle Belt carbonate
Recently renamed Piegan Group (Winston, 2007). Dolomite and dolomitic argillite exposed in southeastern part of map area. Massive unit with karst topography containing m-scale pinnacles and depressions. Unit contains tabular beds from sub-mm to dm scale with molar-tooth structures; brecciated near fault contact with Ysn. No obvious sedimentary structures. About 200 meters exposed in map area.

Ye  Empire Formation
Dolomitic argillite and siltite in southeast corner of map area with cm-scale lenticular beds where exposed. Color ranges
from gray-green to red, finely laminated with local asymmetric ripples. 30 meters exposed in map area.

**Ys**

**Spokane Formation**

Red tabular cm-scale siltite exposed in northeast corner of map area. Lacks obvious sedimentary structures but some float blocks contain fine laminations. About 75 meters exposed in map area.
APPENDIX B

Faunal and Flora lists for the Arikareean Cabbage Patch beds

PLANT GENERA
Taxonomy

Diatomophyceae (diatoms)
   Centrales
      ?Melosira
   Pennales
      (several unidentified forms)

Algae (charophytes)
   Characeae
      (several unidentified forms)

Gymnospermae
   Pinaceae
      Pinus (pine)
   Taxodiaceae
      Sequoia (sequoia)

Angiospermae
   Typhaceae
      Typha (cattail)
   Fragaceae
      Quercus (oak)

INVERTEBRATE GENERA
Taxonomy

Demospongea (fresh water sponges)
   Monaxonida
      Spongillidae gen. sp. indet.

Gastropoda (aquatic and terrestrial)
   Oreohelicidae
      Oreohelix
   Helminthoglyptidae
      Monadenia?
   Valvatidae
      Valvata
   Viviparidae
      Viviparus
   Lymnaeidae
      Lymnaea
   Planorbidae

   Planorbulida
   Biomphalaria
   Pupillidae
   Gastrocopta
   Vertigo
   Pupoides
   Columella
   Succineidae
   Catinella?
   Valloniidae
   Vallonia
   Zonitidae
   Nesovitrea
   Limacidae
   Deroceras
   Punctidae
   Punctum
   Ammonitellidae
   Polygyroidea

   Pelecypoda (pelecypods)
   Sphaeridae
      Sphaerium

   Crustacea (ostracodes)
   Cyprididae
      Cypris
      Cyprinotus
      Candona
   Cyclosyprididae
      Cyclocypris
      Cypria
   Ilyocyprididae
      Ilyocypris

VERTEBRATE GENERA
Taxonomy

Pisces (Osteichthyes)
   Amiiformes
      Amia (bowfin)
   Cypriniformes
      Gila (minnow)
      Amyzon (sucker)
   Perciformes
Lepomis (sunfish)
Sciaenidae gen. sp.
  indet. (drum)

Amphibia
Anura
  ?Ascaphus (tailed frog)
  ?Scaphiopus (toad)
  Tephrodytes (toad)
  ?Rana (large frog)
Urodela
  Taricha (Palaeotaricha)
Plethodon
  (woodland salamander)

Reptilia
Chelonia
  Testudo (tortoise)
  Gen. sp. indet. (pond turtle)

Aves
Galliformes
  Palaeonossax (cracid)
Charadriformes
  Gen. sp. indet. (large dowitcher)
  Gen. sp. indet. (sandpiper)

Mammalia
Marsupialia
  Herpetotherium
    (opossums, four sp.)
  Peradectes
    (opossums, two sp.)
Insectivora
  Ocajila (hedgehog)
  Stenoechinus (hedgehog)
  Amphibechinus (hedgehog)
  Parvericus (hedgehog)
  Gen. sp. indet. (hedgehog)
  Mystipterus (mole)
  Proscaleps (moles, two sp.)
  Gen. sp. indet. (moles, two gen.)
  Dommina (shrews, two sp.)
Pseudotrimylus
  (giant shrews, two sp.)

Lagomorpha
  Palaeolagus (rabbit)
  Archaeolagus (rabbit)
  Megalagus (rabbit)
  Desmatolagus (pika)
  Gripholagomys (pika)

Rodentia
  Downsimus (aplodontid)
  ?Allomys (aplodontid)
  Niglarodon
    (aplodontids, three sp.)
  Meniscomys (aplodontid)
  Gen. sp. indet. (aplodontid, new gen. A)
  Gen. sp. indet. (aplodontid, new gen. B)
  Gen. sp. indet. (aplodontid, new gen. C)
  Gen. sp. indet. (squirrel)
  Pseudotheriodomys
    (eomyid)
  Gen. sp. indet. (eomyids, four sp.)
  Pleurolicus
    (gophers, three sp.)
  Tenuidomys (small gopher)
  Gregorymys (gophers, 3 sp.)
  Entoptychus (gopher)
  Mookomys (pocket mouse)
  Agnotocastor (beaver)
  Monosaulax (beavers)
  ?Capatanka (beaver)
  ?Euhapsis (beaver)
  Eutypomys (beavers, 2 sp.)
  Gen. sp. indet. (beaver)
  Leidymys (mice, two sp.)
  Paciculus (mouse)
  Plesiosminthus
    (jumping mice, two sp.)
  Parasminthus
    (jumping mice, two sp.)

Carnivora
  ?Cynodesmus (coyote-sized canid)
  Gen. sp. indet. (small fox-sized canid)
  Gen. sp. indet. (bobcat-sized felid)
  Gen. sp. indet. (mink-sized mustelid)
  Gen. sp. indet. (weasel-sized mustelid)
  Miohippus (three-toed horse)
  Parahippus?
    (three-toed horse)
  Diceratherium
    (large rhinoceros)
  Gen. sp. indet. (Hyracodon-sized rhino)

Artiodactyla
  Gen. sp. indet. (peccary)
Daeodon
(medium-sized entelodontid)
Kukusepasutanka
(anthracothere)
Megoreodon
(oreodontids, two sp.?)
Desmatochoerus
(oreodontids, three sp.?)
Gen. sp. indet.
(small oreodontid)
Pronodens (small ruminants, two sp.)
APPENDIX C

Faunal list for the Barstovian-Clarendonian Barnes Creek beds

Taxonomy

Amphibia
Numerous unidentified frogs and salamanders

Reptilia
Numerous unidentified lizard and snake vertebrae

Aves
Several unidentified birds

Mammalia
Carnivora
Several unidentified teeth
Insectivora
Several unidentified moles and shrews
Lagomorpha
Leporidae
?Hypolagus sp.
Oreolagus sp.

Rodentia
Mylagaulids
Sciurids
Aplodontids
Eomyids
Cricetids
Heteromyids
Geomyids

Perissodactyla
Equidae
Hypohippus sp. (clarendonian)
Merychippus sp.
Megahippus sp. (clarendonian)
Pliohippus sp. (clarendonian)
Rhinocerotoidae

Artiodactyla
?Blastomeryx
?Dromomeryx sp.
Antilocaparidae
?Merycodus sp. (clarendonian)
Camelidae

Unidentified oreodontids
Salientia
Proboscoidea
APPENDIX D

Sample location map for the Helmville basin, Sixmile Formation sample locations denoted by dots and numbers (ex. SM1) and numbered stars show stratigraphic measurement locations (1 is Oligocene Cabbage Patch Beds and 2 is Miocene Barnes Creek Beds). See Appendix E for Sixmile Formation clast count analysis tables.
APPENDIX E

Tables of Sixmile Formation Gravel clast count. M stands for metasedimentary Belt Supergroup and SS is for sandstone.

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