GEOLOGIC MAP OF THE BUTTE SOUTH 30′ X 60′ QUADRANGLE, SOUTHWESTERN MONTANA

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INTRODUCTION

The Montana Bureau of Mines and Geology (MBMG), in conjunction with the STATEMAP advisory committee, selected the Butte South 30′ x 60′ quadrangle in southwest Montana for mapping because significant progress had been made on this map after 3 years of detailed STATEMAP-funded mapping along major transportation corridors (Vuke, 2004; Vuke and others, 2004; Berg and Hargrave, 2004), additional MBMG mapping in Silver Bow County for geologic hazard assessment (Elliott and McDonald, 2009), and availability of detailed U.S. Geological Survey maps in the Pioneer and Highland Mountains (O'Neill and others, 1996; Zen, 1988; Pearson and Zen, 1985). The Butte South 30′ x 60′ quadrangle was also a priority because numerous important mining properties are within the quadrangle, including part of the world-class Butte copper–molybdenum district, the Highlands district, and the Beal Mountain and Golden Sunlight open-pit gold mines (fig. 1).

The Butte South quadrangle lies in a geologically complex area of southwestern Montana. The Montana fold-thrust belt, the southern margin of the Mesoproterozoic Belt Basin, the Boulder, Pioneer, and Tobacco Root Batholiths, and structures of the Eocene Anaconda Metamorphic Core Complex (O'Neill and others, 2002, 2004) overlap within the quadrangle to create an extremely complicated geologic history. Rock types include Archean and Paleoproterozoic crystalline basement rock, Mesoproterozoic through Cretaceous metasedimentary and sedimentary rock, Cretaceous and Tertiary intrusive rock, Cretaceous and Tertiary volcanic rock, and Tertiary and Quaternary valley-fill and surficial deposits. The quadrangle encompasses rugged alpine terrain in the Highland, Tobacco Root, and Pioneer Mountains and large valleys in the Clark Fork and Missouri River basins.

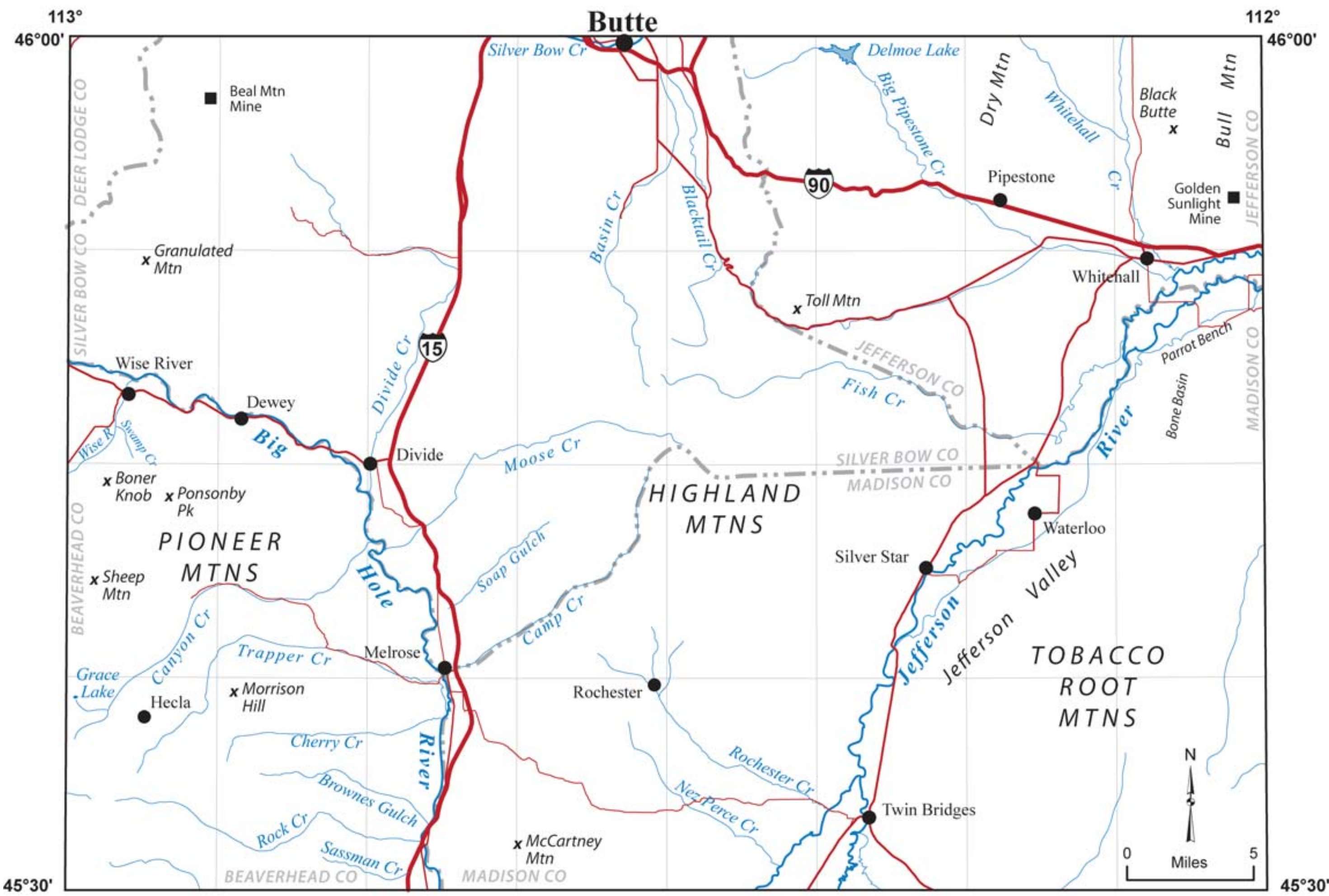


Figure 1. Geographic features in the Butte South 30′ x 60′ quadrangle. Light gray lines are U.S. Geological Survey 7.5′ quadrangle boundaries.

STRATIGRAPHY

Sedimentary rocks in the Butte South quadrangle are assigned to 85 map units that range in age from Quaternary surficial deposits to Mesoproterozoic Belt Supergroup sedimentary and metasedimentary rock. Stratigraphic nomenclature used in this report generally follows that of the previous mapping in the area. In the Highland and Pioneer Mountains, we revise some previous stratigraphic interpretations of Belt and Cambrian units based on new mapping within the Butte South quadrangle and of Belt rocks elsewhere in western Montana.

Stratigraphic revisions for the Highland Mountains

The Highland Mountains (fig.1) encompass the southern margin of the Belt Basin (fig. 2). O'Neill and others (1996) interpreted and mapped the Belt rocks as inclusive of the entire Belt section, from the basal LaHood Formation up through the Missoula Group. In their interpretation, the Cambrian Flathead Formation unconformably overlies the Missoula Group. O'Neill and others (1996) reported a combined thickness of the Ravalli, Piegan, and Missoula Groups of around 750 m (2,460 ft), which is thin compared to elsewhere in the Belt Basin where this interval is at least 6,400 m (20,000 ft) thick (Lonn and others, 2003, 2010).

In contrast, we assign the uppermost Belt strata in the Highland Mountains to the Ravalli Group rather than the Missoula Group, the underlying calc-silicate-bearing siltites and minor quartzites to the Greyson Formation rather than the Helena Formation; and the Newland, Table Mountain, and Moose Formations to facies of the LaHood Formation (fig. 3). We favor this interpretation because it better explains the thin Belt section, and places the Precambrian–Cambrian unconformity at a stratigraphic level consistent with elsewhere in the southern Belt Basin.

The most significant change in Belt stratigraphy in the Highlands is our reinterpretation of the Helena and Empire Formations of O'Neill and others (1996) as Greyson Formation. This interval is characterized by very planar greenish siltite to argillite microcouplets, calc-silicate minerals but no dolomite or calcite, mudcracks, and some mudchips—sedimentary features that are uncharacteristic of the Helena and Empire Formations. However, there are calc-silicate beds at the top of the Prichard Formation (Greyson Formation equivalent in western part of Belt Basin) in the Anaconda Range to the west of the quadrangle. Limestone beds also occur at the top of the Greyson Formation in the Big Belt Mountains (Reynolds and Brandt, 2006) northeast of the Butte South quadrangle.

We interpret the calc-silicate and argillitic interval as representative of the transition from deep-water deposition of the Greyson Formation to shallower, fluvial deposition of the overlying Ravalli Group (fig. 3). The clean quartzite and siltite that we interpret as lower Ravalli Group (possibly the Spokane Formation) are not common lithologies of the Spokane Formation, although Balgord and others (2009) describe similar quartzite beds in the Spokane Formation in the Elkhorn Mountains to the northeast. The clean quartzite may reflect a North American craton source area located east or south of the mapped area.

In our interpretation, the Missoula and Piegan Groups are missing due to Proterozoic-pre-Middle Cambrian erosion and the Flathead Formation rests unconformably on the Ravalli Group. This interpretation is consistent with the level of the unconformity elsewhere in the southern Belt Basin. Northeast of the Highland Mountains near the Golden Sunlight Mine (fig. 1), the unconformity is at a slightly lower stratigraphic level, with the Flathead Formation resting on the Greyson Formation. Farther to the northeast in the southern Elkhorn Mountains, the unconformity is within the Ravalli Group (Reynolds and Brandt, 2006) at a level similar to our placement in the Highland Mountains.

Our assignment of O'Neill and others' (1996) Newland Formation (fig. 3) to the LaHood Formation is consistent with Belt stratigraphy in the nearby Tobacco Root Mountains where the Newland intertongues with and is mapped as part of the LaHood (Tor Nilsen, unpublished mapping; Foster and others, 1993; Vuke and others, 2004).

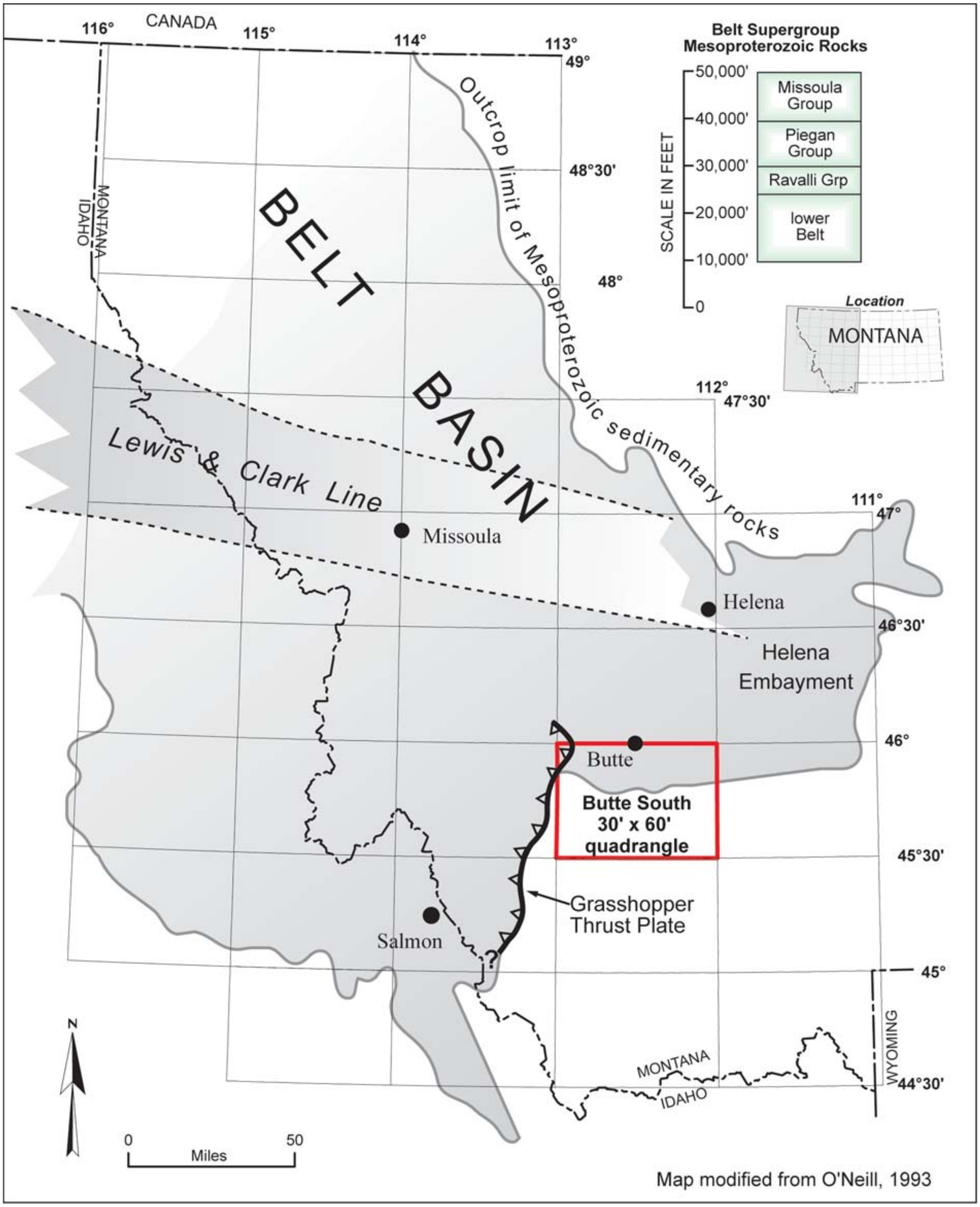


Figure 2. The Butte South 30′ x 60′ quadrangle (red box) relative to the Mesoproterozoic Belt Basin.

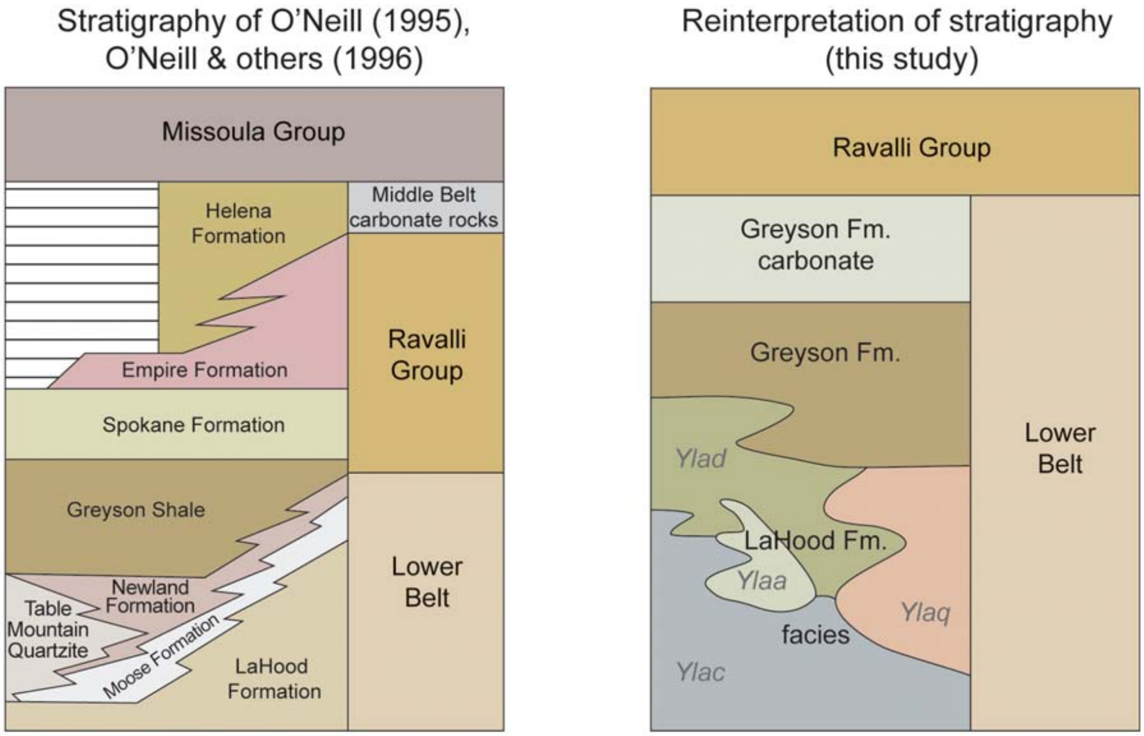


Figure 3. Proterozoic stratigraphic relationships within the Highland Mountains.

Stratigraphic revisions for the Pioneer Mountains

Much of our mapping in the Pioneer Mountains was compiled from Zen (1988) and Pearson and Zen (1985). With some exceptions, we used their stratigraphic assignments for the Belt and Cambrian units.

Zen (1988) interpreted the Black Lion Formation as Cambrian, whereas we interpret it as Mesoproterozoic. Near Grace Lake (fig. 1), quartzite of probable Cambrian age (the Maurice Mountain quartzite of Zen, 1988; the Grace Lake quartzite of Ruppel and others, 1993; the quartzite of Grace Lake (Ꞓglq), this map) rests in angular unconformity on top of the Black Lion Formation (fig. 4). We did not recognize a fault separating the two formations as shown by Zen (1988). Our interpretation of the Black Lion Formation as Proterozoic age, and the overlying quartzite as probable Cambrian age, is consistent with the earlier mapping of Pearson and Zen (1985). Additionally, in the Sheep Mountain area (fig. 1), we interpret a fault contact between the Black Lion Formation and the overlying Cambrian Silver Hill Formation, in contrast to Zen's (1988) interpretation of a gradational stratigraphic contact (fig. 5).

Also in the Sheep Mountain area, the Black Lion Formation appears to rest unconformably on Paleoproterozoic gneiss and amphibolite. Beds in the Black Lion Formation dip away from the gneiss, suggesting a stratigraphic contact with the gneiss exposed in the core of a WNW-trending anticline (plate 1). The gritty quartzite and conglomerate of the Black Lion Formation resemble those of the LaHood Formation, which also rest on basement rocks in the Highland and Pioneer Mountains. Like the LaHood Formation, we interpret the Black Lion Formation as a geographically restricted Belt facies deposited within a steep, perhaps structurally controlled, east-trending segment of the Belt basin's southern margin. Unlike the LaHood Formation, we believe the Black Lion Formation interfingers with upper Belt units (quartzite of Boner Knob, map unit Ybk) rather than lower Belt units (see correlation of map units, plate 1).

Zen (1988) interpreted the "sequence at Swamp Creek" as Proterozoic in age. We believe this interval of interbedded quartz arenite and argillite (map unit Ꞓqba) is Cambrian in age on the basis of trace fossils found in the argillite and possible trace fossils found in the quartzite (best examples are from exposures in northwest corner of the map area west of the Beal Mountain Mine (fig.1). This unit appears to conformably underlie the Hasmark or Silver Hill Formations. The interbedded argillite and quartzite is similar to the Flathead and lower Silver Hill Formations and may represent the base of the Cambrian in the Pioneer Mountains. At Grace Lake (fig.1), the Cambrian (?) Grace Lake quartzite (Ꞓglq)) is overlain by interlayered quartzite and dark argillite similar to our map unit Ꞓqba. However, a near-bedding parallel fault may separate the two units. Similar faults that omit stratigraphic section occur at Sheep Mountain and Hecla (fig. 1).

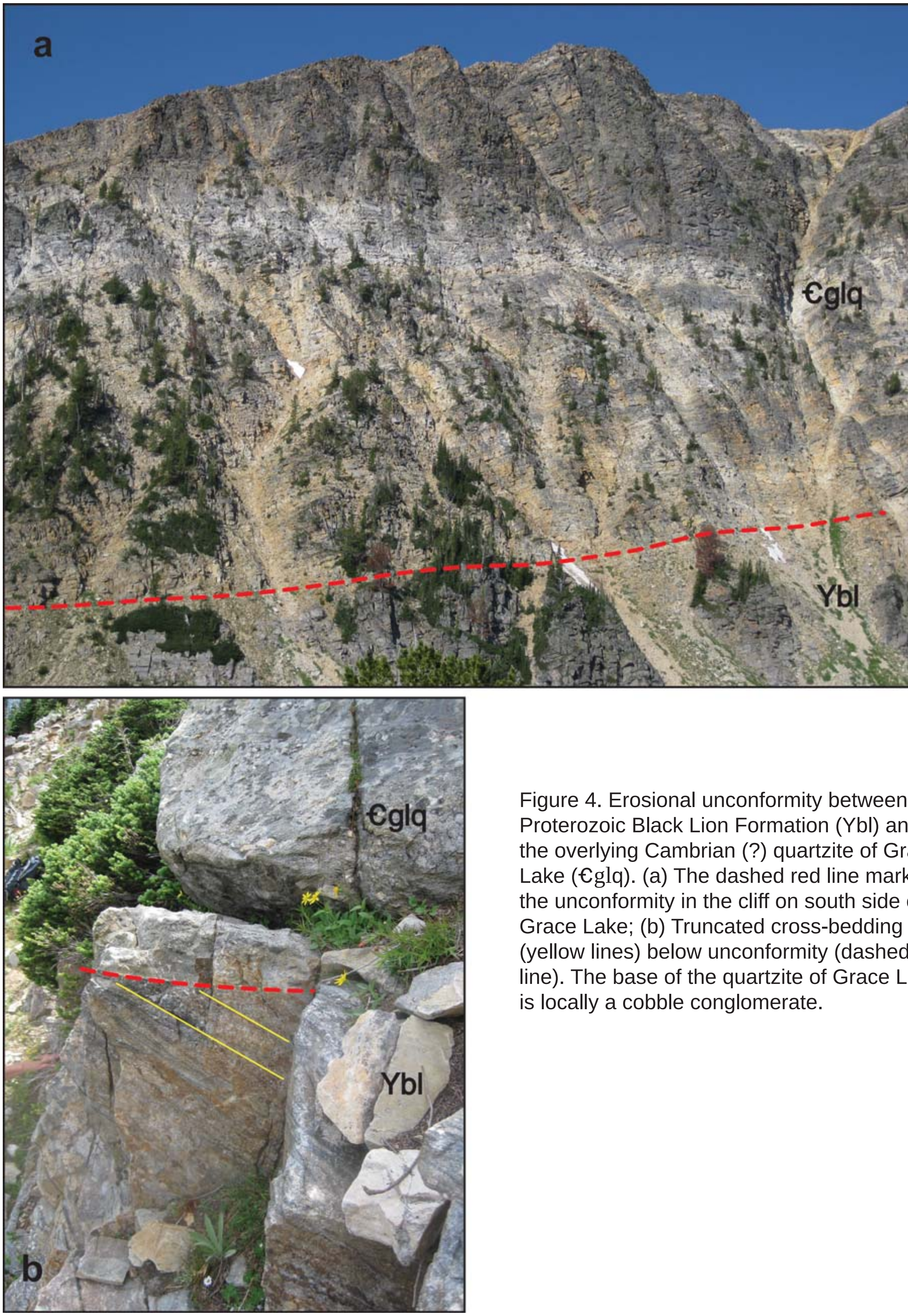


Figure 4. Erosional unconformity between the Proterozoic Black Lion Formation (Ybl) and the overlying Cambrian (?) quartzite of Grace Lake (Ꞓglq). (a) The dashed red line marks the unconformity in the cliff on south side of Grace Lake; (b) Truncated cross-bedding (yellow lines) below unconformity (dashed red line). The base of the quartzite of Grace Lake is locally a cobble conglomerate.

Figure 5. Low angle fault (dashed line) between the Proterozoic Black Lion Formation (Ybl) and Cambrian argillite and quartzite (Єqba). North side of Sheep Mountain, Pioneer Mountains.

IGNEOUS ROCKS

Late Cretaceous and Tertiary igneous rocks outcrop at the surface or underlie a large portion of the Butte South quadrangle (fig. 6). Plutons and stocks of the Boulder, Pioneer, and Tobacco Root Batholiths are differentiated by lithology, texture, age, or location (Smedes and others, 1988; Zen, 1988; Lewis, 1990; Hespenheide, 2003). Cretaceous Elkhorn Mountain and Tertiary Lowland Creek deposits record discrete episodes of volcanic activity. Fine-grained andesitic flows, tuffaceous sediments, and related intrusions of the Elkhorn Mountain sequence have a total thickness of approximately 2,750 m (9,000 ft; Alexander, 1955) and are cogenetic with the emplacement of the Boulder Batholith (Klepper and others, 1957; Smedes, 1966). The 46–50 Ma Trusty Gulch Volcanics (fig. 6; Marvin and others, 1983; Zen, 1988) predate and overlap the timing of 48–52 Ma Lowland Creek volcanism (Isoplatov and others, 1996; Smedes, 1962), and both sequences formed in response to Middle Eocene regional extension. The Lowland Creek Volcanics have a total thickness approaching 1,830 m (6,000 ft) and consist of interlayered rhyolite, dacite, and quartz latite flows and subordinate clastic sediments. Basaltic andesite, andesite, dacite, and rhyodacite flows of the Trusty Gulch sequence are exposed as isolated patches along the east flank of the Pioneer Mountains (figs. 1, 6).

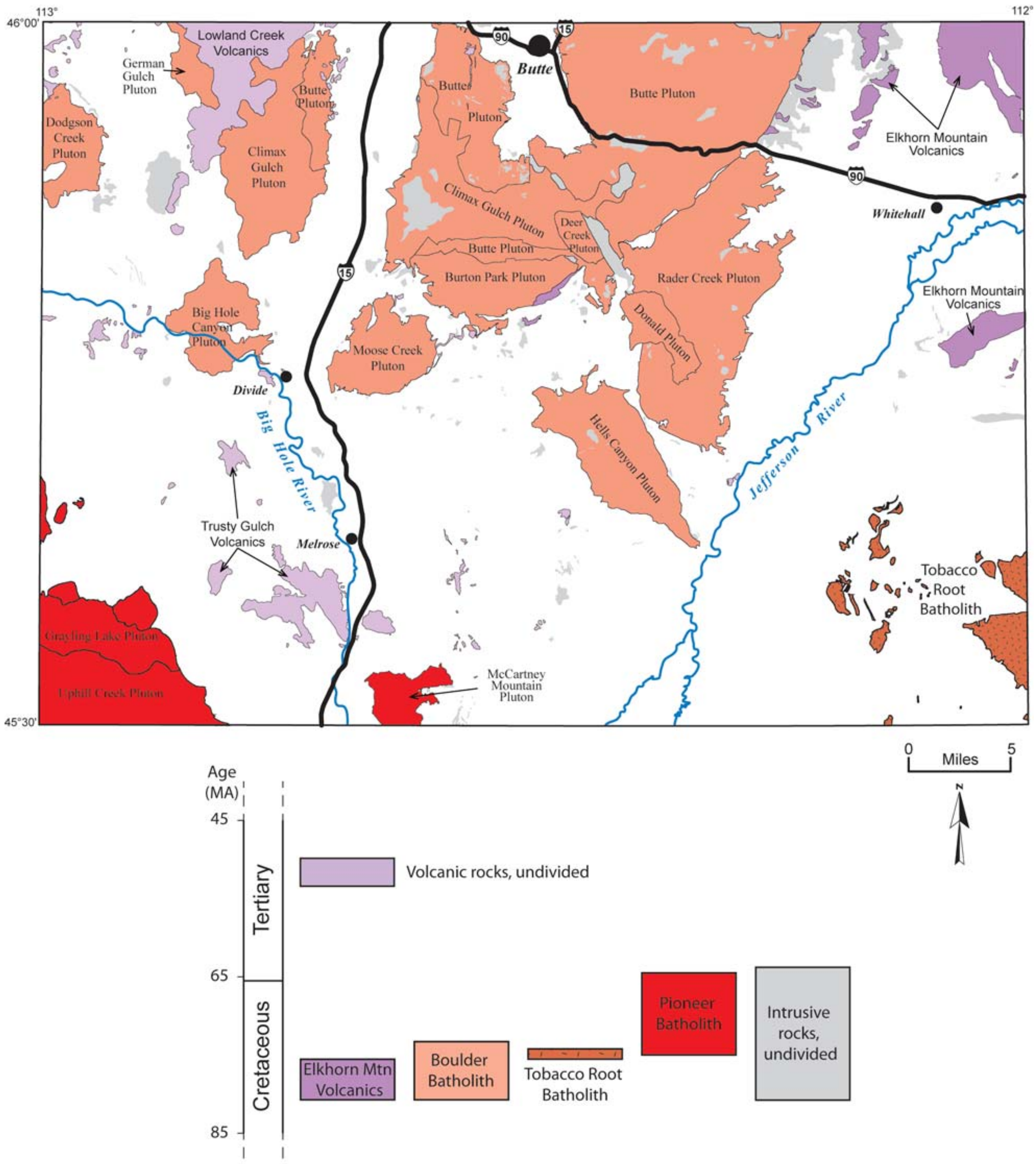


Figure 6. Intrusive and extrusive rocks in the Butte South 30′ x 60′ quadrangle. Individual plutons of the Boulder and Pioneer Batholiths and the more extensive volcanic fields are labeled (after Smedes and others, 1988; Zen, 1988; Lewis, 1990; Hespenheide, 2003). Composition and age of plutons, where determined, are detailed in the description of map units section.

STRUCTURE AND TECTONICS

The long tectonic history of the Butte South area has resulted in complex deformation. Tectonism began with the cryptic 2.47 Ga Beaverhead–Tobacco Root Orogeny, followed by a 1.78–1.71 Ga collision between the Archean Wyoming and Medicine Hat provinces and an intervening island arc (O'Neill, 1998; Harms and others, 2004; Jones, 2008; Krogh and others, 2011); tectonism continues to the present in the form of activity within the Intermountain seismic belt (Smith and Arabasz, 1991). The map area lies at the intersection of a number of important geologic provinces (fig. 7), including the northwestern edge of the Archean Wyoming Province and southeastern edge of the bounding Great Falls Tectonic Zone (O'Neill and Lopez, 1985; Foster and others, 2006); the southern edge of the Proterozoic Belt Basin (Winston, 1986); the easternmost edge of Sevier-Laramide thrusting; the south end of the Cretaceous Boulder Batholith (Berger and others, 2011); and the northern extent of the Cenozoic Basin and Range Province (Reynolds, 1979; Sears and Ryan, 2003). There are many hundreds of structures in the map area, with a variety of styles and orientations, and a comprehensive synthesis is not yet available.

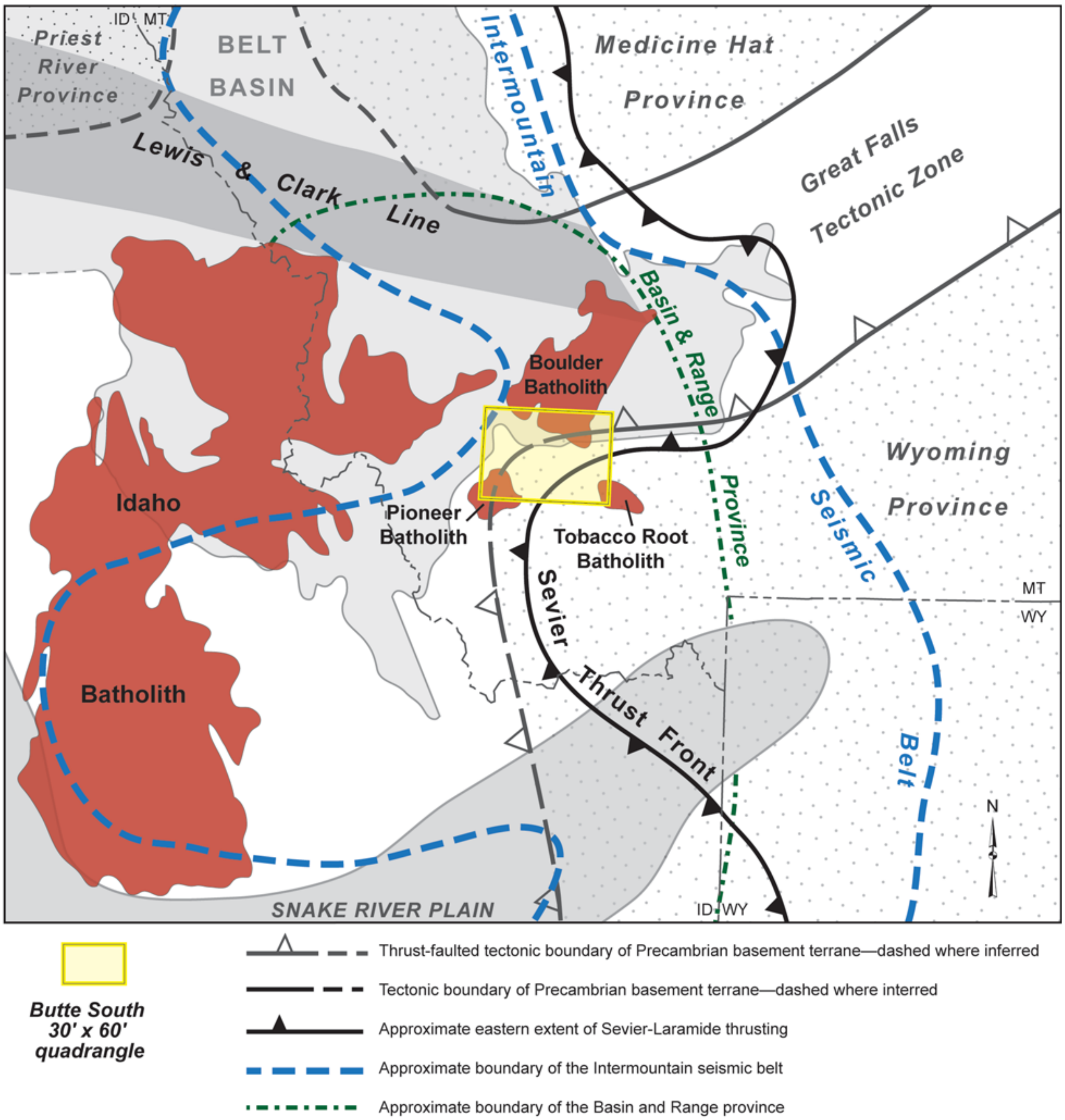


Figure 7. Major Precambrian basement provinces and regional tectonic boundaries and zones in relation to the Butte South 30′ x 60′ quadrangle. The figure also shows the outline of the Proterozoic Belt Basin, the Cretaceous batholitic complexes, and the Tertiary Snake River Plain (modified from Foster and others, 2006; Ross and others, 1991).

We divide the geologic structures in the Butte South quadrangle into five general groups based on differing tectonic origins. Not all structures are easily classified, however, since many have been reactivated one or more times during subsequent tectonic events. Major faults are shown in figure 8.

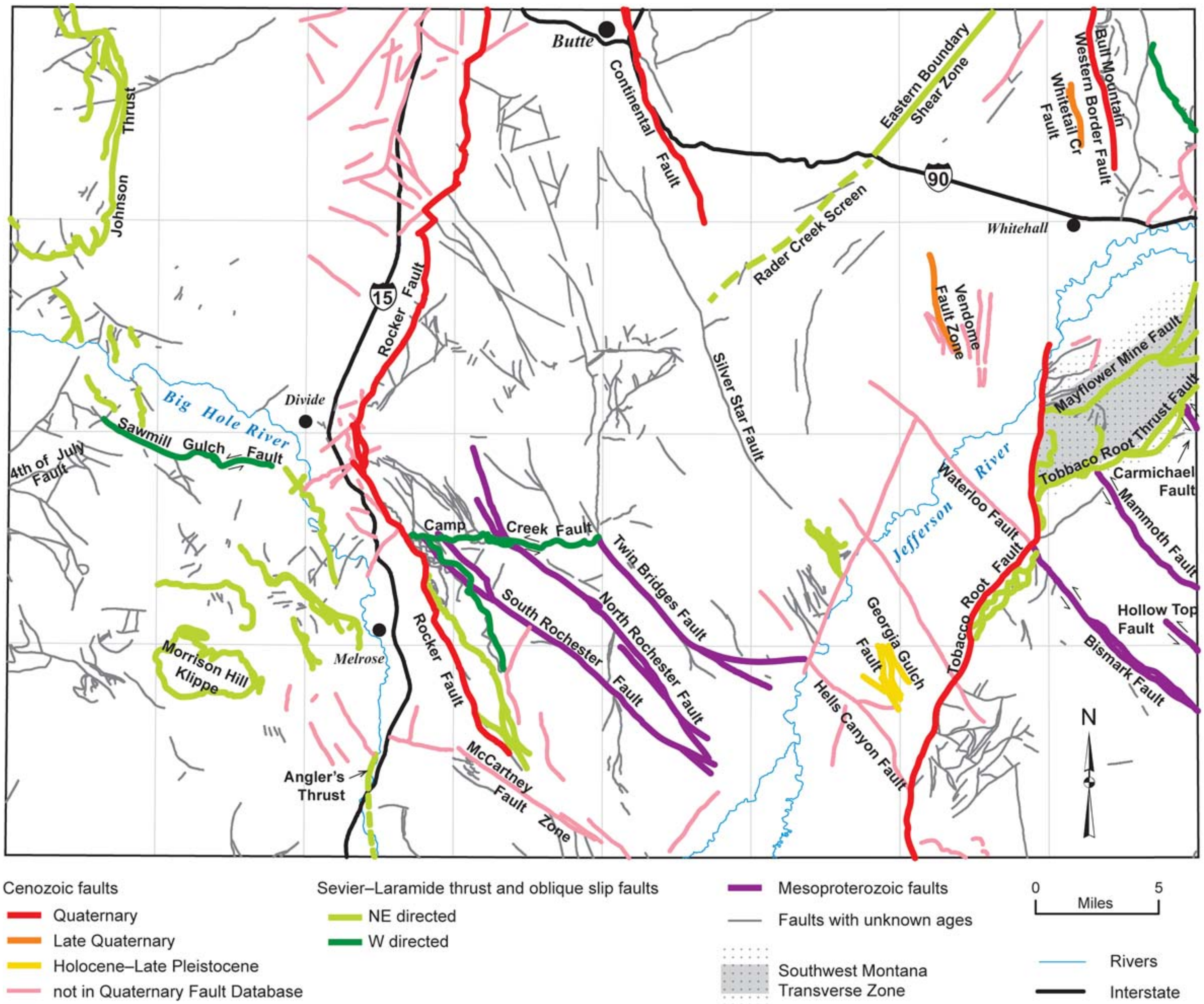


Figure 8. Major faults in the Butte South 30′ x 60′ quadrangle.

Cratonic Blocks

Wyoming Province meta-supracrustal rocks exposed in the Tobacco Root and Highland Mountains (figs. 1, 7) are thought to have been deposited in Late Archean to Early Proterozoic time and subsequently subjected to two episodes of Proterozoic thermotectonism (Roberts and others, 2002). The 2.47 Ga Beaverhead–Tobacco Root Orogeny (Jones, 2008; Krogh and others, 2011) was followed by the high-temperature Big Sky Orogeny between 1.78 and 1.71 Ga (Brady and others, 2004; Harms and others, 2004). The Big Sky Orogeny resulted from the collision of the Archean Wyoming Province and Medicine Hat Block along the northeast-trending Great Falls Tectonic Zone (Mueller and others, 2002; Roberts and others, 2002; Brady and others, 2004; Jones, 2008). The Big Sky event transposed all earlier structures and generated large-scale sheath folds and the dominant northeast-trending structural fabric of the Tobacco Root Mountains.

Small blocks of Paleoproterozoic amphibolite gneisses in the Pioneer Mountains are thought to be part of a similar suite of rocks within the Great Falls tectonic zone (Foster and others, 2006). Trace element geochemistry of magmatic zircons indicates that the boundary between the Great Falls Tectonic Zone and the Wyoming Province runs beneath the Cretaceous Pioneer Batholith (fig. 7; Foster and others, 2012).

Belt Basin

The southern margin of the 1.40 Ga Belt Basin (fig. 7) formed in response to synsedimentary movement along what is now the Camp Creek Fault (McMannis, 1963; Winston, 1986) and along the Willow Creek Fault located east of the quadrangle (Schmidt and Garihan, 1986 a,b). Coarse conglomerate of the LaHood Formation interfingers northward with fine-grained deposits of the lower Belt Supergroup, indicating that the margin was a submarine fan/slope/shelf system (Nilsen, 1991).

This study concludes that the coarse conglomerate of the Black Lion Formation in the northern Pioneer Mountains is similar in age and character to the LaHood Formation, extending the Mesoproterozoic basin margin to the west by at least 20 km (12 miles). The Black Lion Formation is thought to interfinger northward and westward with thick deposits of Boner Knob and Granulated Mountain quartzite, but is now separated from them by the Johnson thrust (Fraser and Waldrop, 1972) and related Sevier-Laramide faults (fig. 8).

The east-west Mesoproterozoic Camp Creek Fault (fig. 8) was reactivated during later events (Schmidt and O'Neill, 1982; Schmidt and Garihan, 1986a; this study) as were the northwest-striking South and North Rochester and Twin Bridges Faults in the Highland Mountains and the Bismark, Mammoth, and Carmichael Faults in the Tobacco Root Mountains. All of these NW-striking faults were interpreted by O'Neill and others (1986), Schmidt and O'Neill (1982), and Schmidt and Garihan (1986b) to be active during Belt Supergroup deposition, even though the Belt basin margin appears to have been a roughly east–west line as reflected by the contact between the base of the LaHood Formation and the crystalline basement rocks in the northern Tobacco Root and Highland Mountains.

Sevier-Laramide Structures

Contractional tectonism above an east-dipping subduction zone in Late Cretaceous time generated the Elkhorn Mountains Volcanic rocks and underlying Boulder Batholith, as well as the multiple generations of low- and high-angle faults, folds, and slaty to spaced, low-grade cleavages that dominate the structures in the Pioneer, Highland, Tobacco Root, and Boulder Mountains. The most obvious structures are related to eastward and northeastward transport of the Grasshopper Thrust Plate (fig. 2) in the eastern Pioneer Mountains (Ruppel and others, 1993), east–northeastward thrusting in the Highland Mountains, and oblique eastward thrusting and strike-slip faulting in the Southwest Montana transverse zone (fig. 8) in the northern Tobacco Root Mountains (Schmidt and O'Neill, 1982).

The Late Mesozoic Grasshopper Thrust System (Ruppel and others, 1993) is represented on the Butte South quadrangle by the Johnson Thrust (Fraser and Waldrop, 1972) which brings a thick section of Mesoproterozoic quartzite over rocks of the craton and Belt basin margin (fig. 8 and plate 1). The related Morrison Hill Klippe in the northeastern Pioneer Mountains is a slice of Mesoproterozoic Belt Supergroup quartzite and Paleozoic rock that lies on folded Cretaceous sedimentary rock along a sub-horizontal fault. In some areas of the Pioneer Mountains, faults that omit stratigraphic section occur at a low angle to bedding. These faults mainly affect the lower Paleozoic section, and have resulted in a great deal of stratigraphic confusion; we propose that they formed during emplacement of this regional-scale thrust sheet.

The top-west directed Camp Creek Fault and the unnamed top-west directed faults at and above the Cambrian–Archean contact east of Melrose are less easily explained. The Camp Creek Fault is a 1- to 4-m-thick brittle-ductile shear zone that dips moderately north with east-plunging shear lineations and oblique top-west kinematic indicators (O'Neill and others, 1996; this study). Along most of its length, the Camp Creek Fault places Mesoproterozoic, lower grade rocks over Paleoproterozoic and Archean, higher grade rocks, but at its west end all of these have been thrust over Cambrian rocks.

The fault at the Cambrian–Archean contact along the east side of the Melrose Valley is a retrograde brittle-ductile shear zone up to 5 m (16 ft) thick with a phyllonitic fabric. The shear zone displays top-west shear indicators including S-C fabrics, over-rotated tension gashes and bookshelf-style antithetic faults. The Cambrian–Archean contact fault and bedding-sub-parallel faults above it place Paleozoic rocks over Precambrian rocks and lower grade metamorphic rocks over higher grade rocks. It is unclear how much stratigraphy has been omitted across these faults, but stratigraphic omission across similar faults in the northern Pioneer Mountains can be demonstrated (as discussed in section on stratigraphy in the Pioneer Mountains).

As many as four generations of Laramide-Sevier folds can be observed. In the western part of the map area, two generations of folds have roughly north-striking axial plane slaty cleavages that are difficult to distinguish on the outcrop scale. The second of the two cleavages dips steeply east and overprints large-scale, east-verging inclined folds. A later fold generation trends east–west, producing dome and basin interference patterns. A steep, east-striking, spaced, axial plane cleavage is locally present.

The Mesoproterozoic North and South Rochester Faults were reactivated probably during late Sevier-Laramide times (O'Neill, 1995; this study). Asymmetric shear fabrics with south-plunging quartz aggregate lineations indicate retrograde metamorphism and east-side-up, sinistral-oblique motion.

Cenozoic and Quaternary Structures

The large valleys in the Butte South area were formed during the Tertiary and Quaternary by motion on bounding Rocker, Continental, Tobacco Root, and Bull Mountain Western Border Faults (fig. 8).

Offset of Tertiary rocks across the South and North Rochester Faults in the south-central part of the map area show that the faults moved again during the Cenozoic Era. The Renova-equivalent rocks between the two faults form a horst created by west-side-down normal displacement on the South Rochester Fault and east-side-down motion on the North Rochester Fault. This is opposite to the sense of motion indicated by shear fabrics in the North Rochester Fault.

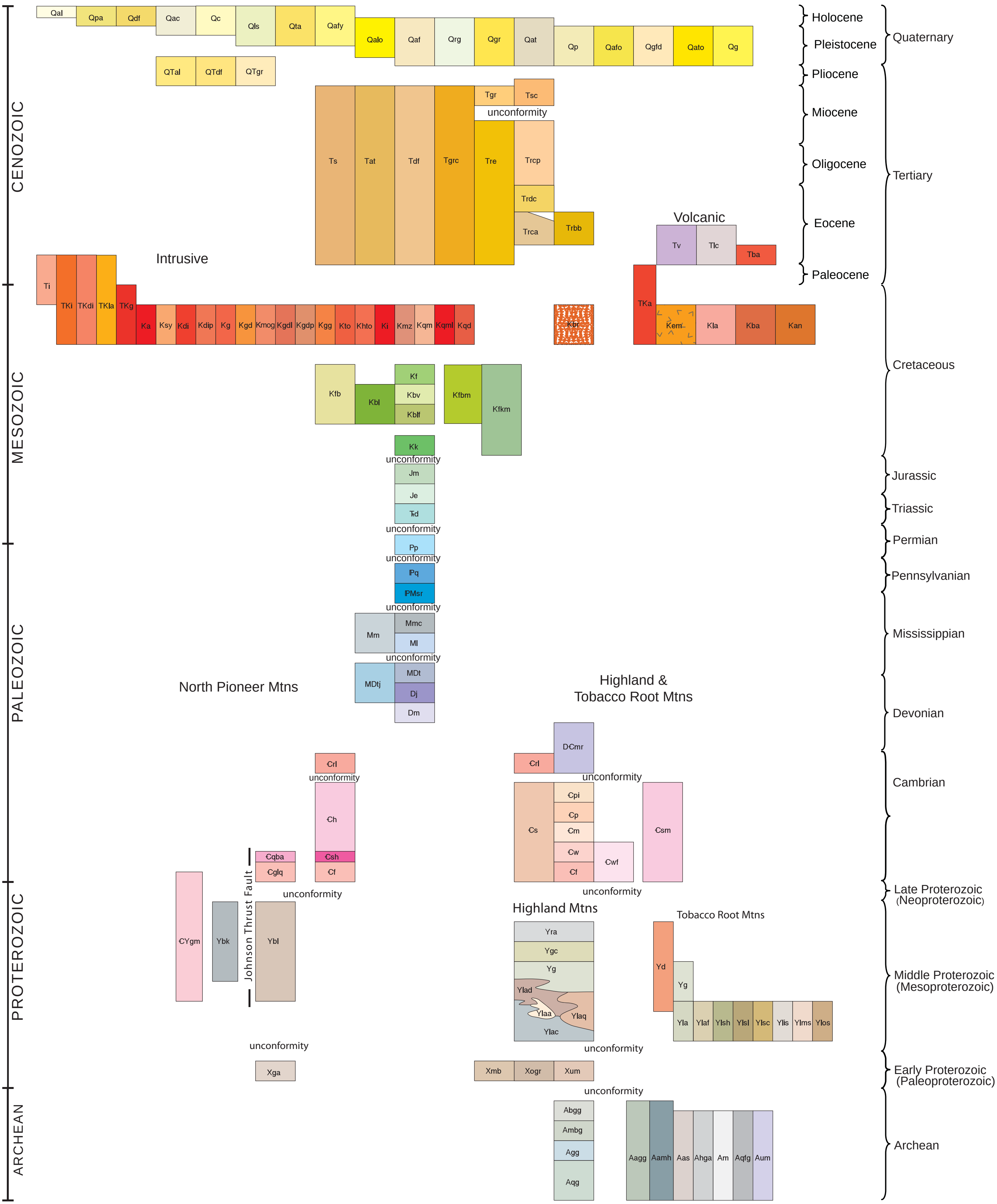
Many of the northeast-trending, brittle faults in the map area are attributed to Cenozoic reactivation of the Great Falls Tectonic Zone (Vuke, 2004). Some of these faults offset Quaternary sediments (Elliott and McDonald, 2009). Figure 8 shows the seven faults in the Butte South quadrangle thought to have been sources of M>6 earthquakes during the past 1,600,000 years (USGS and MBMG, 2006). Based on the quality and precision of available data, the faults are further classified as:

1. Holocene and Latest Pleistocene faults—Georgia Gulch Fault
2. Late Quaternary faults—Vendome and Whitetail Creek Faults
3. Quaternary faults—Rocker, Continental, Bull Mountain Western Border, and Tobacco Root Faults

Detailed information about each of these faults is available at the USGS Quaternary Fault database, http://earthquake.usgs.gov/hazards/qfaults/.

Other faults with probable Quaternary movement include the three faults that cross the upper Jefferson Valley and the McCartney Fault zone.

Correlation of Map Units



BUTTE SOUTH 30´ X 60´QUADRANGLE
DESCRIPTION OF MAP UNITS

Qal **Alluvium (Holocene)**—Gravel, sand, silt, and clay in channels of modern rivers and streams. Clasts generally subrounded to well-rounded, resistant rock. Thickness generally less than 10 m (33 ft).

Qpa **Paludal deposit (Holocene)**—Sand, silt, and organic matter deposited in swamp, marsh, or pond. Thickness probably less than 10 m (33 ft).

Qdf **Debris-flow deposit (Holocene)**—Boulders, and cobbles in a matrix of finer-grained sediment. Clasts poorly sorted, angular, subangular and subrounded. Some fine-grained sediment probably has been removed by erosion leaving coarse clasts as lag. Clasts composed of Paleozoic limestone with some chert in northern deposit and Precambrian LaHood Formation arkose in other deposits. Thickness probably about 15 m (50 ft) in thickest part.

Qac **Alluvium and colluvium (Holocene and Pleistocene?)**—Dominantly sand, silt, clay, and subordinate gravel, deposited on relatively gentle slopes primarily by sheetwash and gravity processes. Variable thickness, generally less than 10 m (33 ft).

Qc **Colluvium (Holocene and Pleistocene?)**—Granule and larger size, unconsolidated, poorly sorted, angular, locally derived clasts deposited on slopes. Thickness generally less than 10 m (33 ft).

Qls **Landslide deposit (Holocene and Pleistocene)**—Mass-wasting deposit that consists of unsorted mixtures of clay- to boulder-size sediment. Includes rotated or slumped blocks of bedrock and surficial sediment, earthflow deposits, and mudflow deposits. Color and lithology reflect that of parent rocks and transported surficial material. Deposit may be stable or unstable. Variable thickness probably less than 30 m (100 ft).

Qta **Talus deposit (Holocene and Pleistocene)**—Coarse, unconsolidated, angular, locally derived clasts in apron-like deposits below relatively steep slopes. Includes some rock-slide deposits. Variable thickness, generally less than 10 m (33 ft).

Qafy **Alluvial-fan deposit, younger than Qaf (Holocene and Pleistocene)**—Gravel, sand, silt, clay, and ash beds, poorly sorted; larger clasts matrix-supported or clast-supported. Younger than adjacent Qaf. Deposited along Whitetail Creek and to the south along the west flank of the Tobacco Root Mountains. Deposits of both Qaf and Qafy display fan morphology, but Qaf deposits are much smaller in aerial extent and sediment volume.

Qalo **Alluvium, older than Qal (Holocene and Pleistocene)**—Gravel, sand, silt, and clay deposited by rivers and streams prior to deposition of Qal. Adjacent to, but with surfaces slightly higher than Qal. Includes sand, silt, clay, and organic matter of floodplain deposits at surface.

Qaf **Alluvial-fan deposit (Holocene and Pleistocene)**—Gravel, sand, silt, clay, and ash beds; poorly sorted with large clasts matrix-supported or clast-supported. Deposits have retained significant evidence of original alluvial fan morphology. Qaf deposits in one area are not necessarily age equivalent to Qaf in other areas. Variable thickness, probably less than 25 m (80 ft).

Qrg **Rock-glacier deposit (Holocene and Pleistocene)**—Angular rock debris and boulders in lobate deposit, frozen together by interstitial ice. Thickness generally less than 10 m (33 ft).

Qgr **Gravel deposit (Holocene and Pleistocene)**—Gravel, sand, silt, and clay; poorly sorted angular to moderately well rounded. Gravel clasts dominantly cobble size and smaller, but may include small boulders.

Qat **Alluvial-terrace deposit (Holocene and Pleistocene)**—Gravel, sand, silt, and clay fluvial deposits older than Qal and Qalo, at elevations above modern channels and floodplains. Clasts generally subrounded to well-rounded, resistant rock. Thickness generally less than 10 m (33 ft).

Qp **Pediment deposit (Pleistocene)**—Sediment veneer on pediment surface. Clasts range from dominantly pebble size or smaller to moderately rounded or rounded gravel clasts that may include small boulders. Thickness generally that of the largest clast size.

Qafo **Alluvial-fan deposit, older than Qaf (Pleistocene)**—Gravel, sand, silt, and clay; poorly sorted, larger clasts generally matrix-supported. Deposits lack original alluvial-fan morphology and have been dissected by erosion in many places, leaving remnants of the original fan. Qafo deposits in one area are not necessarily age-equivalent to Qafo deposits elsewhere, and age is relative only to younger alluvial fans in the immediate area.

Qgfd **Glacial-fan deposit (Pleistocene)**—Gravel, sand, silt, and clay with numerous boulders in a poorly sorted, locally derived deposit associated with Fish Creek that has retained fan morphology. Interpreted as deposited by glacial outburst floods (Dresser, 1996; Bartholomew and others, 1990).

Qato **Alluvial-terrace deposit, older than Qat (Pleistocene?)**—Cobble and pebble gravel; well-sorted with sandy matrix. Clasts composed dominantly of Proterozoic quartzite and igneous rocks with calcium carbonate rinds. Thickness about 6 m (20 ft).

Qg **Glacial deposits (Pleistocene)**—Primarily till and outwash deposited by mountain glaciers. Locally derived, poorly sorted, unconsolidated, bouldery deposits with clasts as large as 3 m (10 ft) in diameter.

QTal **Alluvium (Pleistocene and Pliocene?)**—Gravel, sand, silt, and clay south of Divide; dominantly well-rounded pebbles and small cobbles in a matrix of sand and silt, interbedded with sandy, locally red clay. Clasts dominantly Proterozoic quartzite with subordinate granitic rock. Thickness as much as 90 m (300 ft).

QTdf **Debris-flow deposit (Pleistocene and Pliocene?)**—Unsorted gravel with boulders as much as 3 m (10 ft) across composed of granite and aplite similar to local bedrock. Some are lag deposits lacking fine-grained sediment. Locally, distinct layers represent multiple debris flow events. Thickness as much as 25 m (80 ft).

QTgr **Gravel (Pleistocene and Pliocene?)**—Cobbles and boulders as much as 30 cm (12 in) across; well-rounded, dominantly quartzite and conglomerate derived from Proterozoic meta-sedimentary rocks. Deposits generally occur on higher erosional surfaces in the Pioneer Mountains. Thickness not determined.

Ts **Sediment and sedimentary rock, undivided (Tertiary)**—
McCartney Mountain: Deposits of unknown affinity along west side of McCartney Mountain.

Rocker area: Very pale orange to grayish orange, soft, unconsolidated to moderately indurated clay, silt, and sand with subordinate gravel. Lenses of cobbles contain volcanic, granite, aplite, chert, and chalcedony clasts. Includes some small debris flows containing granite, aplite, and volcanic boulders as much as 2 m (6.5 ft) across. Poorly exposed and thickness not determined.

Tat **Alluvial-terrace deposit (Tertiary)**—Pebbles or pebbles and cobbles in sandy matrix. Isolated outcrops along Jefferson River southeast of Whitehall at elevations higher than Qat. Thickness as much as 25 m (80 ft).

Tdf **Debris-flow deposit (Tertiary)**— (O’Neill and others, 1996) Granules to boulders in a matrix- or clast-supported deposit with a sandy matrix. Largest clasts are small to large boulders, depending on location. Deposits unconformably overlie Archean to Tertiary rocks. West of the Big Hole River near Melrose, dominantly volcanic, chert, quartzite, and small amounts of argillaceous, carbonate, and plutonic clasts. Maximum thickness not known.

Tgr **Gravel deposit (Miocene)**—(O’Neill and others, 1996) Yellowish red to brownish gray pebbles, cobbles, and small boulders; angular to rounded, unconsolidated to weakly consolidated, deeply weathered, composed mainly of quartzite and minor granitic rocks in sand matrix; locally interlayered with white and pale brown to yellowish gray, lensoidal, volcaniclastic sandstone and mudstone; locally capped by a case-hardened calcic paleosol. Thickness as much as 50 m (164 ft).

Tgrc **Gravel deposit, coarse-grained (Tertiary)**—Gravel and conglomerate with clasts as large as small boulders in a channel-fill deposit near Pipestone. Clasts almost entirely derived from the Boulder Batholith. Channel exposed along I-90 near Jefferson Valley margin. Thickness about 25 m (80 ft).

Tsc **Sixmile Creek Formation (Miocene and Pliocene?)**
Whitehall area: (Kuenzi and Fields, 1971) Grayish orange and yellowish orange, generally unconsolidated sandstone and conglomerate with clasts ranging from fine sand to small boulders. Upper part at Parrot Bench south of Whitehall is grayish orange, immature, volcanic glass-bearing, granular, coarse arkose; immature, very fine-grained feldspathic,

vitric arenite; feldspathic vitric siltstone; and feldspathic, volcanic glass-bearing, montmorillonite mudstone.
Silver Star area: Light gray to light brown unconsolidated to cemented, conglomerate or breccia with poorly sorted clasts that range from angular to well-rounded, but are generally no larger than small boulder size. Includes well-rounded metamorphic crystalline rock and quartzite clasts.

Rochester area: Poorly sorted gravel of angular to well-rounded Proterozoic and Archean clasts 2–30 cm (0.8–12 in) across. Locally well cemented, with sandy cross-bedded matrix. Thickness greater than 3 m (10 ft).

Nez Perce–Twin Bridges area: (Feinstein and Reid, 2010) Unconsolidated well-rounded clasts as much as 45 cm (18 in) in diameter with mean diameter of 22 cm (8.6 in). Clasts dominantly brown, red, pink, and purple quartzite and well-cemented sandstone fragments, probably from the Proterozoic Belt Supergroup. Clasts of Archean metamorphic rock absent or sparse. Thickness as much as 170 m (560 ft).

Melrose area: Unconsolidated, cobble-size clasts of platy, angular LaHood Formation rocks from the Moose Creek to the Soap Gulch areas. In the Soap Gulch area, clasts also include limestone, conglomerate, and other lithologies derived from rocks in the immediate area. Locally cemented with calcium carbonate in Soap Gulch and Camp Creek areas, and interbedded with fine-grained sandstone and argillic siltstone with floating, locally derived, angular or subangular granules and pebbles. Exposed thickness about 90 m (300 ft).

Divide–Rocker area: Cemented to unconsolidated arkose granule conglomerate; clasts derived from weathered monzogranite in local area. Local small pods of breccia or subangular conglomerate with clasts of monzogranite, hornfels, and subordinate limestone derived from the local area. Local rounded boulders of monzogranite in matrix of monzogranite granules. Finer grained in northern part of map area with many granule- to pebble-size clasts floating in a matrix of finer grained sediment interbedded with arkose-granule conglomerate. Includes Barstovian and Clarendonian or Hemphillian vertebrate fossils, indicating a middle Miocene to late Miocene, or late Miocene age. Thickness 25–34 m (80–110 ft).

Tre **Renova Formation, undivided (Tertiary; Eocene, Oligocene, and early Miocene)—**
Melrose area: Light orangish pink and very light gray, tuffaceous, sandy siltstone, and fine-grained sandstone, tuff, and bentonitic mudstone, with sparse lenses of coarser clasts, primarily volcanic that range from granules to small cobbles. Contains Chadronian (Eocene) vertebrate fossils in the Trapper Creek area (Tabrum and Nichols, 2001) and unidentifiable fossil bone fragments to the south. Thickness about 150 m (500 ft; Richards and Pardee, 1925).

Sassman Gulch area: (Tysdal and others, 1994) Light gray to pale yellowish brown and grayish orange-pink sandstone, siltstone, and local claystone. Sandstone, fine- to coarse-grained, calcareous in some areas, and locally contains boulders as large as 25 cm (10 in) in diameter.

Rochester area: Light yellowish to medium brown, slightly bentonitic mudstone with flecks of organic matter.

Trcp **Renova Formation, Cabbage Patch Member (Tertiary; early Miocene)**—Pinkish tan, tuffaceous siltstone and poorly sorted arkosic sandstone with lenses of very poorly size-sorted, angular to subangular clasts of locally derived hornfels, quartzite, monzogranite, granodiorite, and limestone. Lenses vary greatly in size. Clasts within lenses are as much as 1 m (3 ft) across. Upper part of unit is white, light gray, and yellowish siltstone and fine-grained sandstone with local diatomite beds and weakly developed calcareous root horizons at the top. Coarse-grained fluvial arkose or granitic granule conglomerate present at base. Quartz, feldspar, and igneous lithic grains, which are primarily plutonic, comprise as much as 97 percent of sand-size material (Schwartz, 2010). Exposed thickness about 60 m (200 ft) in quadrangle, but as thick as 700 m (2,300 ft) to the west in the Flint Creek basin east of Drummond (Rasmussen, 1989).

Trdc **Renova Formation, Dunbar Creek Member (Tertiary; Eocene and Oligocene)—**
Dry Mountain area: Grayish orange and very pale brown, bedded tuffaceous siltstone and mudstone with locally abundant lenticular arkose and conglomeratic lenses. Contains Chadronian and Orellan (Eocene and Oligocene) fossils (Kuenzi, 1966). Thickness about 180 m (600 ft).

Moose Creek area: Very light gray, tuffaceous siltstone and mudstone with lenses of angular clasts. A fossil retrieved from deposit was identified as Orellan (Oligocene; Alan Tabrum, written communication, 2009).

Trca Renova Formation, Climbing Arrow Formation (Tertiary, Eocene)—
Pipestone area (middle to late Chadronian (33.6–37.7 Ma), Kuenzi and Fields, 1971): Montmorillonite mudstone and vitric siltstone with lenses of submature arkose. Thickness 55 m (180 ft).

Upper Jefferson Valley (Petkewich, 1972): Olive gray montmorillonitic mudstone and alternating sandstone and mudstone. Small exposures in footwall of Tobacco Root Mountains range-front fault.

Melrose area: Dominantly greenish brown bentonitic mudstone; yellowish, hard, micaceous claystone and siltstone that weathers to chips, and red siltstone and shale. Other lithologies include polymictic pebble conglomerate with rounded clasts of light-colored igneous rock, brown chert, and Proterozoic quartzite; breccia of igneous rock floating in yellowish tan tuffaceous, fine-grained sandstone; brown and dark brown, coarse-grained arkose and lithic arkose, locally manganese-cemented; and black shale.

Trbb Renova Formation, Bone Basin Member (Tertiary; Eocene, Oligocene, and early Miocene?)—Very light gray, yellowish gray, and olive gray, fossiliferous and locally oölitic or pisolitic limestone, marl, montmorillonite mudstone, and thin beds and stringers of chert and silicified limestone interbedded with matrix-supported granule or pebble conglomerate, sand, silt, and ash. Fossils include algal structures, gastropods, ostracodes, pelecypods, diatoms, and vertebrates that suggest a paludal environment (Kuenzi, 1966) and root casts that indicate subaerial exposure. Silicified limestone interpreted as caliche (Ripley, 1987). Paleosols abundant (Hanneman, 1989). Sedimentary structures include crossbedding and ripple marks. Contains an elongated north–northwest-trending belt of cross-bedded coarse sandstone and granule conglomerate about 0.5 to 1.25 m (4 ft) thick, 200–800 m (⅛- to ½-mi wide), 2,414 m (1½ mi) long, composed almost exclusively of granitic rock fragments (Kuenzi, 1966). Chadronian age (Eocene) determined by fossils, but may extend to as young as Arikareean (Oligocene and Early Miocene) (Axelrod, 1984). Composite thickness of map unit approximately 520 m (1,700 ft; Kuenzi, 1966).

Tv Volcanic rocks, undivided (Eocene)—Dominantly dark gray and black basalt, basaltic andesite, andesite, dacite, and rhyodacite flows that weather dark gray or orangish red; and andesite agglomerate and flows. Subordinate reddish scoria, pink to reddish rhyolite flows, and rhyolite welded tuff and volcanic breccia. Includes the Trusty Gulch Volcanics (Zen, 1988) exposed along the east flank of the Pioneer Mountains.

Tlc Lowland Creek Volcanics (Eocene)—Complexly interlayered volcanic and volcaniclastic sequence (Smedes, 1962) consisting of a laterally discontinuous basal conglomerate with quartz monzonite, aplite, volcanic and lithic fragments, and lenses of arkosic siltstone and sandstone. Upper sequences consist of slightly to densely welded tuff, flow breccias consisting of blocks of quartz monzonite, welded tuff, and other volcanic debris, tuff breccia, lava flows of light to dark gray, grayish red, and brown porphyritic rhyolite, dacite, and quartz latite, and yellowish gray to very light-gray, ash-flow tuff. Estimated thickness as much as 1,850 m (6,080 ft).

Tba Basalt (Eocene)—(Chadwick, 1996) Flows at Golden Sunlight Mine, southern Bull Mountain, dated 49.9 ± 1.6 Ma.

Ti Intrusive rock (Eocene)—Porphyritic quartz latite and related intrusive rock associated with the Lowland Creek Volcanics (Smedes, 1967d).

TKi Intrusive rock (Late Cretaceous or Eocene)—Syenite and hornblende-phyric monzonite on Bull Mountain.

TKa Andesite (Late Cretaceous or Eocene)—(Dixon and Wolfgram, 1998) Porphyritic basaltic andesite on Bull Mountain, blocky to massive, 40–50 percent plagioclase phenocrysts that average 5 mm to 1 cm (0.2–2 in) within a deep red to gray matrix. Silicified and argillic along contact with Paleozoic limestones.

TKdi Diorite, syenogabbro, and gabbro (Paleocene and/or Late Cretaceous)—Small plugs, dikes, and sills related to the Boulder Batholith, but with uncertain age relationships (O'Neill and others, 1996; du Bray and others, 2009).

TKg Granite (Paleocene and Late Cretaceous)—Two-mica, massive, light gray, coarse granite and porphyritic granite. Coarse granite is uniform textured without obvious foliation, except locally where it is defined mainly by biotite alignment. Muscovite forms euhedral intergrowths with biotite and also occurs as rare, large to small single crystals and alteration products. Many small dikes of aplite and rare pegmatite. Clifford Creek Granite of Zen (1988) which has K-Ar ages on biotite of 64.6 ± 2.1 Ma and 64.9 ±2.2 Ma, and an 40Ar/39Ar age of 65.6 ± 1.4 Ma.

TKla Lamprophyre (Tertiary and/or Cretaceous)—(Dixon and Wolfgram, 1998) Porphyritic sill-like lamprophyre in northwest part of map.

Kem Elkhorn Mountains Volcanics (Cretaceous)—Black, green, red, reddish purple, and gray basaltic andesite, andesite, basalt, latite, and trachyandesite flows and intrusive rock; welded and air-fall tuff; volcanic mudflows, breccia, conglomerate, and sandstone.

Ka Aplite (Cretaceous)—Fine- to coarse-grained leucocratic aplite, pegmatite, alaskite, and related rocks. Pods and stocks are typically granophyric, grading internally from aplite to pegmatite.

Kan Andesite (Cretaceous)—Sills that pre-date folding in the Tobacco Root Mountains.

Kla Latite (Cretaceous)—(Chadwick, 1996) Porphyritic phenol-latite intrusive with rhyolite whole-rock composition in Golden Sunlight Mine area on southern Bull Mountain.

Kba Basalt (Cretaceous)—(Prostka, 1966) Dikes, sills, and irregular bodies associated with diorite porphyry north of Pipestone. In some areas, basalt contains conspicuous pyroxene plagioclase phenocrysts.

Ksy Syenite (Cretaceous)—Sills and irregular bodies that intruded the Archean and Paleozoic rock in the Tobacco Root Mountains near Twin Bridges.

Kdi Diorite (Cretaceous)—Diorite and minor syenogabbro and gabbro plugs, dikes and sills.

Kdip Diorite porphyry (Cretaceous)—(Protska, 1966) Green, gray, and purple, with phenocrysts of labradorite, pyroxene, and hornblende; locally brecciated or conspicuously banded.

Kg Granite (Cretaceous)—

Grayling Lake Pluton of the Pioneer Batholith: Medium to coarse, pink to gray porphyritic granite and granodiorite with K-feldspar phenocrysts up to 1 cm (0.4 in; Zen, 1988). Biotite is the major mafic mineral, with subsidiary hornblende and accessory sphene, epidote, magnetite, apatite, muscovite and zircon. K-Ar age 74.1 Ma (Marvin and others 1983), U-Pb zircon age 72.2 ± 1.7 Ma (Murphy and others, 2002).

Younger granitic bodies associated with the Boulder Batholith: Small granite and quartz monzonite intrusions within and around larger plutons (Smedes and others, 1988).

Kgd Granodiorite (Cretaceous)—

McCartney Mountain Pluton: Composite pluton with four phases ranging in composition from fine-grained granodiorite to granite. A quartz monzodiorite phase yielded a K-Ar biotite cooling age of 74.1 ± 1 Ma.

Big Hole Canyon Pluton: Hornblende-biotite granodiorite with mafic inclusions, locally ranging to diorite, quartz diorite, and granite. Contains accessory magnetite, apatite, and sphene (Hespenheide, 2003). K-Ar hornblende age of 77.2 ± 3.1 Ma and K-Ar biotite age 77.1 ± 3.1 (Tilling and others, 1968), Ar-Ar hornblende age 85.7 ± 85.2.6 Ma, and Ar-Ar biotite age 74.7 ±1.2 Ma (Zinter, 1982).

Dodgson Creek Pluton: Mostly medium gray and medium-grained, slightly porphyritic and gneissic granodiorite and tonalite (Lewis, 1990). Pluton has a K-Ar date on biotite of 76.4 ± 2.6 Ma from sample from adjacent Wise River quadrangle (Marvin and others, 1983).

German Gulch Pluton: Medium-grained granodiorite to diorite with biotite, hornblende, and accessory augite, magnetite, apatite, sphene and zircon. A K-Ar age of 74.8 Ma has been determined from a thermally reset biotite from a sample from the Beal Mountain Mine (Hastings and Harrold, 1988).

Hungry Hill Pluton: Medium gray, fine- to medium-grained granodiorite and tonalite (Lewis, 1990).

Granodiorite plutons of the Boulder Batholith: Coarse- and fine-grained, light to dark gray, pinkish and bluish gray granodiorite that locally varies to monzogranite and quartz monzonite. Hornblende and biotite are dominant mafic minerals.

Burton Park Pluton: U-Pb zircon age 77.6 ± 0.8 Ma (du Bray and others, 2009).

Moose Creek Pluton: U-Pb zircon age 74.2 ± 0.5 Ma (du Bray and others, 2009).
Rader Creek Pluton: U-Pb zircon age 80.4 ± 1.2 Ma (Lund and others, 2002).
Uphill Creek Pluton: U-Pb zircon age 72.2 and 72.17 Ma (Murphy, 2002). This pluton is part of the Pioneer Batholith.

Kmog Monzogranite (Cretaceous)—Butte Pluton, which forms the main component of the Boulder Batholith. Medium- to coarse-grained equigranular, fine-grained equigranular, and fine-grained porphyritic granite, as well as finer grained granitic rocks with textures of granophyre, porphyry, and aplite. Mostly light to dark gray varying to pinkish or brownish gray. Mafic minerals are biotite and hornblende with up to 4 percent accessory sphene, magnetite, zircon, apatite, and allanite. U-Pb zircon ages of 74.7 ± 0.4 Ma, 76.4 ± 0.7 Ma and 76.5 ± 0.7 Ma (du Bray and others, 2009).

Kgdl Granodiorite, leucocratic (Cretaceous)—Medium-grained, light gray granodiorite with zones of pink alkali-feldspars >1 cm (0.4 in) across. Confined to the Donald Pluton of the Boulder Batholith, which has a U-Pb age of 74.7 ± 4 Ma U-Pb (du Bray and others, 2009).

Kgdp Granodiorite, porphyritic (Cretaceous)—Light gray, medium- to coarse-grained porphyritic granodiorite and quartz monzonite. The Hells Canyon Pluton, with a U-Pb age of 73.7 ± 0.5 Ma (du Bray and others, 2009) contains pink alkali feldspar phenocrysts that locally exceed 8 cm (3 in) across, and accessory biotite and hornblende. In the southwest part of the map, porphyritic granodiorite forms a marginal phase of the Grayling Lake Pluton.

Kgg Granite, granophyric (Cretaceous)—Deer Creek Pluton, leucocratic aplite, and pegmatite with graphic texture with a U-Pb age of 76.9 ± 0.6 Ma (du Bray and others, 2009).

Kto Tonalite (Cretaceous)—(Smith, 1970) Medium-grained and equigranular to porphyritic tonalite with pink potassium feldspar megacrysts in about ⅓ of the exposures. Platy elongated ferromagnesian minerals emphasize flow structures. Potassium feldspars are poikilitic; quartz occurs as intergrowths with the feldspars. Granitoid texture is common and subhedral-euhedral crystals are completely interlocking. Quartz is interstitial and feldspars are zoned.

Khto Hornblende tonalite (Cretaceous)—(Smith, 1970) Medium-grained and equigranular to porphyritic tonalite with 5–13 percent hornblende. Elongated ferromagnesian minerals emphasize flow structures. Potassium feldspars are poikilitic; quartz occurs as intergrowths with the feldspars. Granitoid texture is common and subhedral-euhedral crystals are completely interlocking. Quartz is interstitial and feldspars are zoned.

Ki Intrusive rock, undivided (Cretaceous)—Syenite, monzonite, and other intrusive rocks in the Tobacco Root and Pioneer Mountains.

Kmz Monzonite (Cretaceous)—(Prostka, 1966) Coarse-grained, mafic monzonite.

Kqm Quartz monzonite (Cretaceous)—
Tobacco Root Mountains (Johns, 1961): Light gray, medium- to coarse-grained with sodic plagioclase, orthoclase, quartz, biotite, hornblende, and augite. Locally porphyritic with phenocrysts of sodic plagioclase.

Highland Mountains: Climax Gulch Pluton of the Boulder Batholith. Coarse- to fine-grained, strongly porphyritic quartz monzonite and granodiorite (Smedes and others, 1973). U-Pb zircon age of 76.3 ± 0.5 Ma (du Bray and others, 2009).

Kqml Quartz monzonite, leucocratic (Cretaceous)—Homestake Pluton and related bodies. Silicic rocks with textures varying between aplite and pegmatite with few mafic minerals. U-Pb zircon age of 75.3 ± 0.7 Ma (du Bray and others, 2009).

Kqd Quartz diorite and tonalite (Late Cretaceous)—Medium- to coarse-grained, gray to dark gray quartz diorite and tonalite. Weakly porphyritic hornblende and diorite, 40 Ar/39 Ar age date on hornblende of 74 ± 2.1 Ma (Snee, 1982). Crops out locally in southern part of Big Hole Canyon Pluton (Hespenheide, 2003).

Kbr Breccia (Cretaceous)—Cemented deposits of angular fragments of Archean or subordinate intrusive rocks in the Tobacco Root Mountains.

Kfb Frontier and Blackleaf Formations, undivided (Cretaceous)

Kfbm Frontier and Blackleaf Formations, metamorphosed (Cretaceous)—Hornfels and subordinate quartzite. The Frontier and Blackleaf Formations could not be distinguished where metamorphosed by the McCartney Mountain Pluton.

Kfkm Frontier, Blackleaf and Kootenai Formations, metamorphosed (Cretaceous)—Hornfels and subordinate quartzite produced by contact metamorphism associated with the Big Hole Pluton.

Kf Frontier Formation (Cretaceous)—

East Pioneer Mountains (Tysdal and others, 1994): Dominantly gray, brown, brownish gray, and greenish gray siltstone and mudstone, and subordinate medium- to coarse-grained, and locally very coarse-grained sandstone; conglomerate; limestone, and minor porcellanite. Mudstone, siltstone, limestone, and sandstone beds form fining-upward depositional cycles tens of meters thick. Sandstone and conglomerate are rich in quartz and chert. Conglomerate clasts are rounded pebbles and small cobbles. Thickest and coarsest conglomerate beds at Rock Creek. Volcaniclastic sandstone and bentonitic mudstone in upper part. Lower 100-200 m (330-660 ft) is distinctive brown to brownish gray siltstone and mudstone south of the Brownes Gulch area, but to the north, those beds are not present and a conglomerate bed occurs at the base in the Brownes Gulch–Cherry Creek areas. Thickness about 900 m (3,000 ft).

McCartney Mountain: Medium and dark gray, grayish brown, brown, and greenish gray fine-grained, bedded, somewhat silicified mudstone (argillite), siltstone, sandstone, and local beds of dark purple or greenish porcellanite. Distinctive brown to brownish gray siltstone and mudstone characteristic of the basal Frontier Formation in much of the East Pioneer Mountains was not recognized on McCartney Mountain. Base of formation mapped at base of first thick sandstone bed (after Dyman and Nichols, 1988) above green porcellanite of the underlying Vaughn Member of the Blackleaf Formation. Exposed thickness about 300 m (1,000 ft).

Kbl Blackleaf Formation, undivided (Cretaceous)

Kbv Blackleaf Formation, Vaughn Member (Cretaceous)—

Dickie Peak: Pinkish gray, grayish red, and brownish gray sandstone and siltstone interbedded with mudstone (primarily expressed as covered intervals); medium dark gray and light olive gray porcellanite; subordinate conglomerate beds. Exposed thickness about 700 m (2,300 ft).

Pioneer Mountains, south of Rock Creek (Tysdal and others, 1994; Dyman and Tysdal, 1998): Olive green, yellowish green, bright green, and gray green, hard, dense, and calcareous siltstone and porcellanitic (silicified) mudstone. Subordinate gray, greenish gray and olive gray, fine- to medium-grained, and locally coarse-grained sandstone, with high percentage of volcaniclastic debris, and matrix-supported conglomerate and conglomeratic sandstone with clasts mostly of chert and quartzite. An association of distinctive maroon mudstone and siltstone, gray freshwater limestone or locally very calcareous mudstone and siltstone, dark gray shale, and bright green porcellanite is present in uppermost part. Top of member mapped at top of porcellanite bed, interbedded with micritic limestone, that directly overlies the highest maroon mudstone. Two porcellanite beds approximately 210 m (690 ft), and 170 m (560 ft) below the top of the Vaughn in the eastern Pioneer Mountains near Rock Creek yielded precise U-Pb ages of 96.9 ± 0. [±1.0] and 96.2 ± 0.4 [±1.1] Ma, respectively (Zartman and others, 1995). Thickness 584–594 m (1,230–1,950 ft).

Pioneer Mountains, Brownes Gulch-Cherry Creek areas: Diminished silicification is reflected by fewer porcellanite beds, more abundant shale, and white, reddish, or greenish tuffaceous beds than to the south. Top of member mapped at top of porcellanite bed interbedded with micritic limestone that directly overlies the highest maroon mudstone, as to south. In part of this area the Vaughn Member was previously mapped as the Kootenai Formation (Hutchinson, 1948; Zen, 1988). Exposed thickness about 180 m (600 ft).

Trapper Creek area (Theodosis, 1956): Jade-green argillite interbedded with arkosic, reddish brown to gray sandstone. Thickness about 180 m (600 ft).

McCartney Mountain: Abundant green, greenish gray, gray, and purple porcellanite beds, and gray and brown fine-grained volcanic-rich sandstone, siltstone, mudstone, and argillite. Thickness about 180 m (600 ft).

Kblf Blackleaf Formation, Flood Member (Cretaceous)—
Pioneer Mountains (Tysdal and others, 1994):
Upper part: pale brown to brownish gray, fine- to medium-grained and locally coarse-grained to conglomeratic, quartz- and chert-rich sandstone, and conglomerate. Trough crossbedding common in sandstone.
Middle part: dominantly gray mudstone, shale, and minor interbeds of siltstone and quartz-rich sandstone.
Lower part: medium-gray and locally green and red calcareous siltstone and mudstone, gray shale, and gray, calcareous, fine- to medium-grained sandstone that is rich in quartz and chert grains. Thickness 375 m (1,230 ft).
Trapper Creek area (Theodosis, 1956): Black, calcareous shale, greenish gray argillite and massive, crossbedded, "salt and pepper" sandstone. Shale grades laterally into silty, greenish gray argillite and massive sandstone. Thickness 175 m (574 ft).

McCartney Mountain: Gray to yellowish brown, quartz- and chert-rich sandstone with conglomeratic bed at top that contains angular to subrounded imbricated mudstone clasts. Underlain by gray to black, moderately to strongly fissile shale and fine- to very fine grained sandstone as thick as 5 m (16 ft). Underlain by basal gray or brown, fine- to medium-grained calcareous and iron-stained, crossbedded and symmetric ripple-laminated, 87 m (285 ft) thick, massive sandstone with subordinate lithologies of micritic limestone, mudstone, siltstone, and chert. Thickness 165 m (540 ft).

Kk Kootenai Formation (Cretaceous)—
Upper: Light gray gastropod coquina or gastropod-rich limestone that may also contain charophytes and ostrocodes.
Middle: Variegated shale and mudstone, dominated by red, orange, and purple, and subordinate light and medium gray colors, interbedded with light gray quartz- and chert-rich limonitic or non-limonitic, fine- to coarse-grained, poorly to well-sorted, massive or crossbedded, chert-rich, locally conglomeratic sandstone.
Basal: Light brown to yellowish gray quartz- and chert-rich conglomeratic, cross-bedded, sandstone or conglomerate. Combined thickness of all units about 250 m (820 ft).

Jm Morrison Formation (Jurassic)—Green, red, and gray variegated mudstone, shale, and siltstone with thin, interbedded yellowish brown to grayish orange, very fine grained sandstone and siltstone beds, and thin, gray limestone beds. Thickness about 105 m (350 ft).

Je Ellis Group (Jurassic)—
Swift Sandstone: Grayish orange, calcareous, limonitic or glauconitic, crossbedded, coarse-grained, fossiliferous, quartz sandstone. Thickness about 20 m (65 ft).

Rierdon Limestone: Light gray, oölitic, fossiliferous limestone, and calcareous shale. Quartz and chert sand grains are interspersed throughout some of the limestone beds, and locally the quartz and chert clasts are granule or small pebble size. Thickness about 15 m (50 ft).

Sawtooth Formation:
Upper: Yellowish brown, fossiliferous mudstone; thin-bedded, fossiliferous, carbonaceous siltstone and dolomite; and light gray, thin-bedded, fossiliferous limestone.
Lower: Gray to dark brown conglomeratic quartz and chert sandstone of variable thickness, with subangular to subrounded chert and light gray limestone pebbles. Formation not present on western part of map. Thickness of both units 0–25 m (0–80 ft).

T̵Rd Dinwoody Formation (Triassic)—Interbedded shale, limestone, and sandstone characterized by brown weathered surfaces and presence of phosphatic pelecypod Lingula. Upper part is massive calcareous, rippled sandstone beds as much as 1 m (3 ft) thick with shaly interbeds and massive, gray, pinkish gray weathering limestone as much as 1 m (3 ft) thick. Lower part dominantly olive drab, chippy-weathering, hard fissile shale with interbedded dark brown weathering, silty limestone beds 10 cm (4 in) or thinner. Thickness about 150 m (492 ft).

Pp Phosphoria Formation (Permian)—Upper part is massive, brownish gray to dark gray, laminated or thin- to thick-bedded chert with subordinate beds of dark olive brown, phosphatic sandstone and phosphatic, pink weathering shale. Where present, lower part is light tan gray massive dolomite containing tubular to nodular, yellow and brown chert and bedded brown to grayish tan chert. Black, oölitic phosphate beds and fish-bone-bearing beds up to 0.5 m (1.6 ft) thick occur near contact with upper chert part. Thickness 30–95 m (100–310 ft) in the Melrose area.

ℙq **Quadrant Formation (Pennsylvanian)**—Light gray to light yellowish brown quartzitic sandstone and vitreous quartzite, massive to thick-bedded. Minor yellowish orange siltstone and locally, near top and base, thin- to medium-bedded light gray silty or sandy dolomite and limestone. Often brecciated near faults. Thickness variable, up to 200 m (650 ft) in the Pioneer Mountains (Zen, 1988) and 55 m (180 ft) in the Tobacco Root Mountains.

ℙMsr **Snowcrest Range Group (Pennsylvanian and Mississippian)**—(Wardlaw and Pecora, 1985; Zen, 1988; and Theodosis, 1956, mapped as Amsden Formation). Thickness of group about 120 m (395 ft).
Conover Ranch Formation: Pale reddish brown to pale reddish purple, thin-bedded calcareous mudstone and subordinate limestone, calcareous sandstone and siltstone, and limestone-pebble conglomerate. Mudstone with characteristic light tan oval spots a few millimeters (⅛–¼ in) across.

Lombard Formation: Upper part is light olive gray, thin- to thick-bedded fossiliferous limestone with thin interbedded silty limestone, siltstone, and shale. Lower part is olive gray and medium red to pale reddish purple calcareous mudstone.

Kibbey Formation: Pale red, pale gray, and pale yellow, thin- to medium-bedded siltstone, sandstone, and mudstone. Interbedded limestone and evaporate solution breccia in middle part of formation.

Mm **Madison Group, undivided (Mississippian)**—Undivided Mission Canyon and Lodgepole Formations, mapped in areas of Highland and Tobacco Root Mountains where structural complexity or metamorphism obscure distinctions between formations.

Mmc **Mission Canyon Formation (Mississippian)**—Light gray, thick-bedded, fossiliferous, cliff-forming limestone with irregular chert bands, and local solution breccia zones in the upper part. Thickness 360 m (1,190 ft).

Ml **Lodgepole Formation (Mississippian)**—Gray, fossiliferous, thin-bedded, slope-forming limestone. Basal Cottonwood Canyon Member is a thick dark shale and siltstone. Thickness 300 m (990 ft).

MDtj **Three Forks and Jefferson Formations, undivided (Mississippian and Devonian)**

MDt **Three Forks Formation (Mississippian and Devonian)**—Brown, argillaceous, fossiliferous limestone interlayered with black to dark gray carbonaceous shale, grayish green shale, and light tan, silty sandstone. Thickness 75 m (250 ft).

Dj **Jefferson Formation (Devonian)**—Dark gray to brown, mottled, fetid, coarsely crystalline, resistant dolomite. Upper Birdbear Member is light gray, microcrystalline dolomite. Where Birdbear Member is absent, upper part of formation often is brecciated. Thickness 190-305 m (620-1,000 ft).

D€mr **Maywood and Red Lion Formations, undivided (Devonian and Cambrian)**—Thickness of combined formations 36 m (120 ft).

Dm **Maywood Formation (Devonian)**—
Camp Creek area: Grayish red purple, grayish orange pink, very pale orange, and medium gray, argillaceous and/or silty and quartzose dolomite, and dolomitic sandstone. Thickness 40 m (130 ft).

Tobacco Root and Bull Mountains: Purplish to light gray limestone and sandy dolomite underlain by yellow, orange, and red calcareous sandstone and siltstone. Thickness 18 m (60 ft).

€s **Sedimentary rock, undivided (Cambrian)**—Pilgrim, Park, Meagher, Wolsey, and Flathead Formations. Combined in northern part of Highland Mountains based on the original mapping by O'Neill and others (1996).

€sm **Sedimentary rock, metamorphosed (Cambrian)**—Highly deformed quartzite, marble, and schist from middle Cambrian protoliths, forms a discontinuous screen of country rock between the Butte and Rader Creek Plutons near Toll Mountain.

€rl **Red Lion Formation (Cambrian)**—
Pioneer Mountains: Lower part consists of red, reddish brown, and yellowish brown siltstone and shale, some calcareous, with locally abundant trace fossils. Upper part is light to dark gray micritic limestone with thin interbedded discontinuous argillite layers. The argillite stands in relief on weathered surfaces and imparts a wavy,

ribbon-like structure to the bedding. Flat-pebble conglomerate and mottled beds due to burrowing are relatively common. Weathered argillite surfaces often display distinct, grayish red and pale red, Liesegang banding. Thickness approximately 25 m (82 ft).

Tobacco Root and Bull Mountains: Dark brown or greenish shale and light to dark brown thin-bedded, shaly sandstone interlayered with limestone and dolomite; underlain by basal brownish gray, laminated, silty limestone. Thickness 18 m (60 ft).

Ꞓh **Hasmark Formation (Cambrian)—**
Pioneer Mountains: Light gray to bluish gray thin to very thick-bedded, medium crystalline dolomite with minor magnesium limestone intervals. Basal part contains common peloids succeeded upward by oölitic and pisolitic intervals, algal-mat carbonate, minor intraformational conglomerate, and thin quartzite beds. Weathers very light gray with a gritty laminated surface. Minor chert nodules and bedded chert a few centimeters to decimeters thick distinguish this unit from the Jefferson Formation (Dj). Adjacent to plutons, metamorphosed to white to light bluish gray, massive dolomite. Thickness variable due to deformation, ranging from 200 to 500 m (650–1,640 ft; Zen, 1988; Obert, 1962).

Ꞓpi **Pilgrim Formation (Cambrian)—**
Tobacco Root and Highland Mountains, and Bull Mountain/Black Butte: Medium to light gray, mottled, resistant fine-grained limestone and dolomite, and thin-bedded laminated slope-forming dolomite. Mottling not as conspicuous as in Meagher Formation. Thickness 110 m (360 ft).

Ꞓp **Park Formation (Cambrian)—**
Tobacco Root and Highland Mountains, Bull Mountain/Black Butte: Green fissile shale with thin beds of feldspathic sandstone and limestone flat-pebble conglomerate, locally abundant trilobite fossils. Thickness 45–60 m (150–200 ft).

Ꞓm **Meagher Formation (Cambrian)—**
Tobacco Root Mountains and north, and Highland Mountains: Medium to dark gray fine-grained resistant limestone mottled with lighter gray, black, gold, or rust-colored irregular dolomite that grades into nodular-bedded, gray limestone with closely spaced, thin, very irregular, tan or rust-colored, dolomitic shale partings and oölitic or pelletal limestone. Silicified in Twin Bridges area. Thickness 225 m (740 ft).

Ꞓsh **Silver Hill Formation (Cambrian)—**
Pioneer Mountains: Lower part is thin-bedded, olive green to olive gray, micaceous shale and argillite with interbedded reddish quartzite and siltite. Upper part is interbedded nodular and silty limestone, thin-bedded siltstone, and sandstone. Dark gray limestone beds commonly contain wavy yellow brown silty seams that impart a “black and gold” color to rock. Near intrusive contacts, shale is metamorphosed to grayish black hornfels. Thickness as much as 122 m (400 ft).

Ꞓwf **Wolsey and Flathead Formations (Cambrian)—**western Tobacco Root Mountains.

Ꞓw **Wolsey Formation (Cambrian)—**
Tobacco Root and Highland Mountains; Bull Mountain/Black Butte: Olive green, irregularly bedded micaceous shale and fine-grained arkosic sandstone interbedded with tan to green fissile shale and thin limestone, and flat-pebble conglomerate. Lower part contains iron-rich, glauconitic sandstone and deep red pelletal hematite layers. Flute casts common. Thickness 28–80 m (90–260 ft).

Ꞓf **Flathead Formation (Cambrian)—**
Tobacco Root Mountains and north: Upper fine- to medium-grained, pinkish gray sandstone about 18 m (60 ft) thick, and lower fine-grained, more resistant pinkish gray, silica-cemented sandstone 10–12 m (33–40 ft) thick. Sandstone mature to submature. Crossbedded in Tobacco Root Mountains. Flat chips of green argillite occur at the base on Black Butte. Thickness 45–90 m (150–300 ft).

Pioneer and Highland Mountains: Very light gray, pinkish gray or yellowish brown quartzose sandstone or orthoquartzite, and subordinate well-cemented granule to pebble conglomerate. May be massive or crossbedded and contain subordinate, grayish green to pale red, micaceous fissile shale beds. Thickness as much as 30 m (100 ft). In the Pioneer Mountains, the Flathead is missing due to nondeposition except in the northwest corner of the map, where the Flathead Formation underlies the Silver Hill Formation.

A basal unconformity places the Flathead on Archean rock south of the Camp Creek Fault in the Highland Mountains and south of the Jefferson Canyon Fault in the Tobacco Root Mountains. North of these faults, the Flathead overlies Proterozoic rock.

Ꞓqba Quartzite and argillite (Cambrian?)—
Pioneer Mountains: Quartzite and black to green argillite in couplets and couples. Argillite has a lumpy appearance and locally contains trace fossils. At Swamp Creek and Ponsonby Peak, the quartzite-argillite unit is overlain by a thick (>15 m [>48 ft] thick), white, mostly fine-grained, well-sorted, quartzite that appears to be clean in hand sample but is actually very feldspathic: five samples contained 15–25 percent K-spar and 10–20 percent plagioclase. At Hecla (where unit is included with the Silver Hill Formation), a cobble conglomerate bed is interbedded with argillite-cobbles are white quartzite. Exposed sections exhibit evidence of a fault that is sub-parallel to bedding and that omits stratigraphic section. Ꞓqba is equivalent to the Swamp Creek sequence of Zen (1988) and Ruppel and others (1993), and is also thought to be equivalent to the Silver Hill Formation (unit Ꞓsh). Thickness unknown.

Ꞓglq Quartzite of Grace Lake (Cambrian?)—
Pioneer Mountains: White to light gray, fine- to medium-grained quartzite. Contains coarse intervals with rounded quartzite pebbles and angular grains of quartzite, quartz, and feldspar; some beds of "grit." However, lacks the pink and red quartzite and chert clasts of the Black Lion Formation. Grains are subrounded to sub-angular, and moderately to well-sorted, although coarser intervals are poorly sorted. Contains abundant well-rounded quartz grains. In hand sample, the finer grained intervals appear clean, but 7 samples contained 15–25 percent K-spar, and 5–10 percent plagioclase. Flat laminations are common, as are trough crossbeds in the coarse intervals. Base is exposed at Grace Lake, where a low-angle unconformity with the underlying Black Lion Formation is clearly visible. Appears to grade upward into the quartzite and argillite of unit Ꞓqba at Grace Lake and in the South Fork of Boulder Creek west of the map area. At Hecla, a low-angle fault obscures relationships at the upper contact. Equivalent to the quartzite of Grace Lake of Ruppel and others (1993), the Maurice Mountain quartzite of Zen (1988), and the Cambrian or Proterozoic quartzite of Pearson and Zen (1985). Thickness unknown but at least 75 m (244 ft) exposed at Grace Lake.

Ygm Quartzite of Granulated Mountain (Mesoproterozoic and Cambrian?)—
Pioneer Mountains: White to dark gray, medium- to coarse-grained quartzite with common black mud chips and some black argillite beds. Thin- to thick-bedded with abundant trough crossbeds and flat laminations, often defined by dark minerals. The unit coarsens upward to a pebble- to cobble-bearing conglomerate. Five samples showed 10–25% potassium feldspar and highly variable 1–20% plagioclase content. Exposed in the hanging wall of the Johnson Thrust. Base and top not exposed, but at least 183 m (600 ft) thick at Granulated Mountain.

Yd Diabase (Proterozoic)—
Highland and Tobacco Root Mountains (Vitaliano and Cordua, 1979, O'Neill and others, 1996): Sets of mafic dikes, two high-K quartz-normative types were intruded between 1,120 and 1,130 Ma, one similar to ferrobasalt or ferrogabbro in composition; the other is low in Fe. The oldest set, intruded about 1,455 Ma, is low-K tholeiite composition.

Ybk Quartzite of Boner Knob (Mesoproterozoic)—Pink to maroon, fine- to coarse-grained feldspathic quartzite. Upper part is pink to white, massive, fine- to medium-grained, moderately well-sorted, sub-angular quartzite. Contains sparse well-rounded coarse quartz grains and thin mud chips. Eight slabbed and stained samples showed feldspar content of 10–30 percent K-spar and 3–10 percent plagioclase. Lower part is pink to white, medium-grained to conglomeratic, moderately to poorly sorted quartzite with subrounded to angular grains. Contains sparse well-rounded, frosted quartz grains, well-rounded quartzite cobbles, pink and red chert grains, and angular feldspar and quartz granules. Five samples contained 15–25 percent K-spar and 0–3 percent plagioclase. Thickness unknown, but at least 500 m (1,625 ft) thick at Morrison Hill, where the best exposures occur. Occurs only in the hanging walls of the Johnson Thrust and the 4th of July Fault; the footwalls east of these faults have a different stratigraphy. Described and named by Zen (1988) and Pearson and Zen (1985). Upper part is equivalent to Calbeck's (1975) Belt 2, and lower part is equivalent to the Belt 1 of Calbeck (1975) and the Bonner Formation of Lonn and McDonald (2004).

Ybl Black Lion Formation (Mesoproterozoic)—
Pioneer Mountains: Pink, green, and purple conglomerate containing abundant multi-colored, subangular to rounded lithic fragments. Usually prominently crossbedded, with both trough and high-angle planar crossbeds. Composition is highly variable, reflecting local source areas. Abundant gritty intervals containing angular gneissic, granitic, and dark-colored lithic clasts. Contains distinctive brick-red laminated chert (siltstone?) and pink to purple

quartzite clasts that are usually rounded; these clasts are rare to absent in the overlying Grace Lake quartzite. Five samples showed highly variable composition, but were plagioclase-poor (<5 percent). Contains intervals of light gray, medium-grained, quartz-rich, sub-angular to sub-rounded, well-sorted quartzite containing abundant coarse, round quartz grains. Two samples showed 87–95 percent quartz, 0–3 percent K-spar, and 7–10 percent plagioclase. The upper contact is an angular unconformity in the Grace Lake area and is a fault at Black Lion Mountain and east of Sheep Mountain. The lower contact, poorly exposed in the Sheep Mountain area, appears to be an unconformable contact with the underlying gneiss. Resembles the LaHood Formation of the Highland Mountains. As much as 500 m (1,625 ft) thick.

Yra **Ravalli Group (Mesoproterozoic)**—Predominantly quartzite to siltite couples and couplets. Beds of white to light gray, fine- to medium-grained, quartz-rich sand from 1 cm to 0.5 m (0.5 in to 1.5 ft) thick, containing distinctive coarse, round, frosted quartz grains, alternate with thinner reddish silt beds that are as much as 10 cm (4 in) thick. Some couplets are graded, and some quartzite beds contain cross-laminations. Directly east of the Twin Bridges fault, upper part is locally a subangular pebble to cobble intraformational conglomerate. Near Toll Mountain, the rock is highly deformed gneiss and schist, forming a discontinuous screen of county rock between the Butte and Rader Creek Plutons. Mapped as Missoula Group by O'Neill and others (1996). Estimated thickness about 200 m (655 ft).

Ygc **Greyson Formation, upper calcsilicate member (Mesoproterozoic)**—Mostly very planar greenish quartzite, siltite, and argillite microcouplets and couplets containing calc-silicate minerals, but no dolomite or calcite. Common medium- to coarse-grained clean quartzite lenses from 3 mm to 0.5 m (< 1 in to 1.6 ft) thick containing round frosted quartz grains. Very small-scale flaser bedding common. Soft sediment deformation features and mudcracks that appear to be formed from desiccation are common. Uncommon beds of mud-chip breccia containing coarse, round, frosted quartz grains. Gradational with the underlying LaHood Formation. Unit not present everywhere. Near Toll Mountain, the rock is highly deformed gneiss and schist, forming a discontinuous sheet of county rock between the Butte and Rader Creek Plutons.

Yg **Greyson Formation, undivided (Mesoproterozoic)**—Mostly drab olive, very thin planar beds of siltstone and argillite. Uncommon, thin ripple-cross-laminated beds of very fine grained calcareous quartzite. Uncommon thinly laminated intervals of very planar, dark gray argillite/claystone.

Yla **LaHood Formation, undivided (Mesoproterozoic)**—Tobacco Root Mountains (McMannis, 1963)—Coarse arkose, conglomeratic arkose, and minor arkosic siltite. Uppermost 9 m (30 ft) dark gray, siltite and thin-bedded feldspathic quartzite. At Bone Basin, the LaHood is coarse and contains scattered boulders of gneiss, schist, pegmatite, and marble in the lower part as much as 1.5 m (5 ft) long. Thickness as much as 1,830 m (6,000 ft).

LaHood lithologic facies—Highland Mountains

Ylad **LaHood Formation, dark argillite and carbonate facies (Mesoproterozoic)**—Dark gray to pinkish gray argillite and silty argillite with subordinate calcareous marl-bearing zones commonly associated with finely crystalline to medium-crystalline medium gray limestone. Argillite beds are thin (1–3 cm), massive, and typically separated by beds of tan siltstone with single to multiple flat laminae or very fine-grained quartzite beds. Outcrop and float from this unit are characterized by tabular, centimeter-thick beds that have extremely planar parting surfaces (O'Neill and others, 1996). Unit is thickest adjacent to fault splays of the northwest-trending North and South Rochester faults. Originally mapped as the Newland Formation by O'Neill and others (1996). Interfingers with quartzite facies and coarse facies of LaHood Formation. Estimated maximum thickness exceeds 275 m (900 ft).

Ylaq **LaHood Formation, quartzite facies (Mesoproterozoic)**—Upper part consists of massive white quartzite beds separated by 1- to 5-m-thick upward-fining sequences of intraformational conglomerate, quartzite, siltite, and argillite. Lower part consists of about 250 m (820 ft) of quartzite that is overlain by interbedded clean to argillaceous quartzite, siltite, and argillite. Interfingers with overlying argillite facies and underlying coarse facies. Mapped as the Table Mountain Quartzite by O'Neill and others (1996). Estimated maximum thickness exceeds 500 m (1,640 ft).

Ylaa **LaHood Formation, argillite and siltite facies (Mesoproterozoic)**—Medium gray to tan argillite, siltite, and minor quartzite. Lacks the tabular, blocky beds of the overlying black shale facies and the argillaceous grit unique to the underlying coarse facies. Originally mapped and described by O'Neill and others (1996) as the Moose Formation. Estimated thickness 40–80 m (130–260 ft).

Ylac LaHood Formation, coarse facies (Mesoproterozoic)—Cobble to boulder conglomerate that becomes finer grained laterally, grading first into quartz-pebble conglomerate, then into coarse, argillaceous, lithic grit and arkose. Interfingers with finer grained argillite, siltite, quartzite, and subordinate channels of pebble conglomerate and argillaceous grit. Mapped as the LaHood Formation (proximal and distal facies) by O'Neill and others (1996). Estimated thickness of less than 700 m (2,295 ft) in western parts of Highland Mountains and more than 1,500 m (4,920 ft) in the central Highland Mountains.

LaHood depositional environment facies (Mesoproterozoic)—Tobacco Root Mountains and north (Nilsen, 1991)

Ylaf LaHood Formation, alluvial-fan and fan-delta facies—
Debris-flow component: Reddish to purplish weathering, massively bedded sandstone that lacks internal current-formed sedimentary structures. Displays reverse grading, matrix-supported angular clasts, poor sorting of both matrix and clasts, and isotropic fabrics.

Stratified component: Grayish-weathering, planar-bedded and low-angle crossbedded sandstone, with local shale drapes and interbeds, moderately to well-sorted, sub-angular to rounded clasts and rip-up clasts of shale; local channel-form geometries, and fining-upward cycles at several localities. Shale interbeds characteristically weather to brown and olive brown, and locally exhibit mudcracks, wave ripples, and parallel lamination.

Ylsh LaHood Formation, shelf facies (Mesoproterozoic)—Massive to parallel bedded, pebbly sandstone; stratigraphically between submarine-canyon and alluvial fan facies.

Ylsl LaHood Formation, slope facies (Mesoproterozoic)—Characterized by abundant synsedimentary slumps. Consists dominantly of mudstone with thin siltstone turbidites and graded non-turbidite intra-flow deposits. Highly tectonized because of the lack of competent beds, and appears to consist mostly of sheared and deformed argillite.

Ylsc LaHood Formation, submarine canyon facies (Mesoproterozoic)—Boulder to pebble conglomerate and conglomeratic sandstone that is poorly stratified and highly channelized. Canyons were relatively small and are cut into shallow marine units, so exposures are principally of the upper canyon parts.

Ylis LaHood Formation, inner submarine fan facies (Mesoproterozoic)—
Channel-axis component: Boulder to pebble conglomerate and pebbly sandstone with thin shale interbeds.

Channel-margin component: Argillite with thin interbeds of turbidite siltstone and very fine-grained sandstone.

Ylms LaHood Formation, middle submarine fan facies (Mesoproterozoic)—Characteristic repetitive fining- and thinning-upward sequences with channelized bases and interbedded, thin-bedded overbank turbidites. Overbank turbidites consist of thin, but coarse-grained, laterally discontinuous deposits with abundant small-scale slump folds that generally indicate slumping directions away from channel axes.

Ylos LaHood Formation, outer submarine fan facies (Mesoproterozoic)—Abundant sandstone beds in stacked thickening- and coarsening-upward sequences that display abundant sole markings and characteristic Bouma sequences. Sandstone beds are typically planar, well-graded, and separated by shale intervals. Contains slurried beds with shale rip-up clasts.

Xga Gneiss and amphibolite (Early Proterozoic)—Foliated plagioclase gneiss, augen gneiss, banded fine-grained and coarse-grained gneiss, and amphibolite. Very rare quartzose, slightly calcareous layers. Mapped by Zen (1988) in the Pioneer Mountains east and north of Sheep Mountain, where it is in depositional contact with the overlying Proterozoic Black Lion Formation. Foster and others (2006) obtained a 1.86 Ga U-Pb age interpreted to represent the protolith's crystallization age.

Xmb Mafic dikes and sills (Early Proterozoic)—Dark gray to black, fine-grained, equigranular, hornblende, plagioclase, augite and garnet dikes and sills.

Xogr Igneous and metamorphic rocks, undivided (Early Proterozoic)—Granitic to granodioritic foliated orthogneiss with small leucocratic, medium-grained plugs, and thick sills of granite, aplite and pegmatite. Present as a large sill-like body in Highland Mountains along Camp Creek. Map unit Xi and Xg of O'Neill and others (1996). In southern Highland Mountains, unit consists of a dense swarm of leucocratic quartz-feldspar sills intruded into crystalline metamorphic rock. Map unit Xs of O'Neill and others (1996).

Xum Ultramafic rock (Early Proterozoic)—Black to dark greenish brown, coarse-grained lenses and irregularly shaped pods commonly less than 30 m (100 ft) in length or width but locally more than 1.5 km (1 mi) long. Consists of orthopyroxene, olivine, spinel, hornblende, and magnetite. Mapped along Rochester Creek in southern Highland Mountains (O'Neill and others, 1996).

Highland Mountains Archean Metamorphic Rocks (from O'Neill and others, 1996)

Abgg Biotite garnet gneiss (Archean)—Dark gray to black, medium-grained to very coarse, strongly folded, biotite gneiss-biotite gneiss with abundant quartz feldspar veins.

Ambg Mylonitic biotite gneiss (Archean)—Pink plagioclase porphyroclasts and quartz ribbons in a dark gray to black, medium- to coarse-grained mylonite with minor phyllonite. Composed of quartz, plagioclase, biotite, and sillimanite.

Agg Garnet gneiss and schist (Archean)—Contains discontinuous lenses of marble, quartzite, iron formation, anthophyllite schist, and amphibolite. Gneiss and schist sequence ranges from 0 to 100 m (0–330 ft) thick.

Aqg Quartz-feldspar gneiss and schist (Archean)—Platy, gray to tan, fine- to medium-grained quartz-plagioclase gneiss and schist with minor microcline, biotite, and hornblende; local seams of mylonite and sills of granite.

Tobacco Root Mountains Archean Metamorphic Rocks—(from Vitaliano and Cordua, 1979; O'Neill, 1983)

A**agg Anthophyllite-gedrite gneiss (Archean)**—Light gray to reddish brown, purplish brown, or deep golden brown gneiss and subordinate schist, weathers to dark brown or blackish brown.

Aamh Amphibolite and hornblende gneiss (Archean)—Gray to black, medium-grained, hypidiomorphic, equigranular, moderately foliated to well-foliated hornblende-plagioclase gneiss and amphibolite.

Aas Aluminous schist (Archean)—Contains mineral assemblages of kyanite, sillimanite, quartz, red-brown biotite, garnet, rutile, and locally graphite in various proportions.

Ahga Hornblende-plagioclase gneiss and amphibolite (Archean)—Dark gray to black gneiss and para-amphibolite. Dominant minerals are green or brown hornblende and plagioclase. Almandine porphyroblasts, clinopyroxene, orthopyroxene, cummingtonite, and biotite are commonly present with accessory minerals epidote, sphene, magnetite, and apatite.

Am Marble (Archean)—Light to dark brown-weathering, white on fresh surfaces. Forms prominent ridges. Dominant minerals are calcite and dolomite in a 3:1 ratio.

Aqfg Quartzofeldspathic gneiss (Archean)—Includes plagioclase-microcline-quartz biotite ("granitic") gneiss, plagioclase-quartz-biotite ("tonalitic") gneiss, banded biotite gneiss, aluminous gneiss and schist, gedrite gneiss, and garnet gneiss.

Plagioclase-microcline-quartz-biotite gneiss: Light gray to light pinkish gray, medium-grained, weakly to moderately foliated gneiss ranging from granodiorite to syenogranite.

Plagioclase-quartz-biotite gneiss: Gray, medium-grained, inequigranular, weakly to moderately foliated, tonalitic gneiss. Includes some trondhjemitic and granodioritic gneiss.

Banded biotite gneiss: White, light gray, dark gray, and black, medium-grained, well-foliated, inequigranular, tonalitic to quartz monzonitic gneiss, commonly migmatitic.

Aluminous schist and gneiss: Gray to dark brownish gray, medium-grained, inequigranular, generally well foliated, commonly micaceous, gneiss, and schist containing aluminosilicate minerals.

Gedrite gneiss: Brown to grayish brown, moderately well foliated, medium-grained, gedrite gneiss. Generally occurs in small lenses and concordant layers in other Archean rocks.

Garnet gneiss: Highly garnetiferous assemblage of various colors that includes biotite-garnet schist, sillimanite-garnet schist, garnetiferous quartzite, quartzite, garnetiferous quartzofeldspathic gneiss, corundum gneiss, gedrite schist, cummingtonite schist, and garnetiferous amphibolite (Vitaliano and Cordua, 1979).

Aum **Ultramafic rock (Archean)**—Dark green to black, coarse-crystalline lenses, pods, and small plugs composed mainly of olivine, hornblende, orthopyroxene, and clinopyroxene. Includes mafic to intermediate gneiss, hornblende-plagioclase gneiss, amphibolite, granulite, and intrusive metabasite.

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