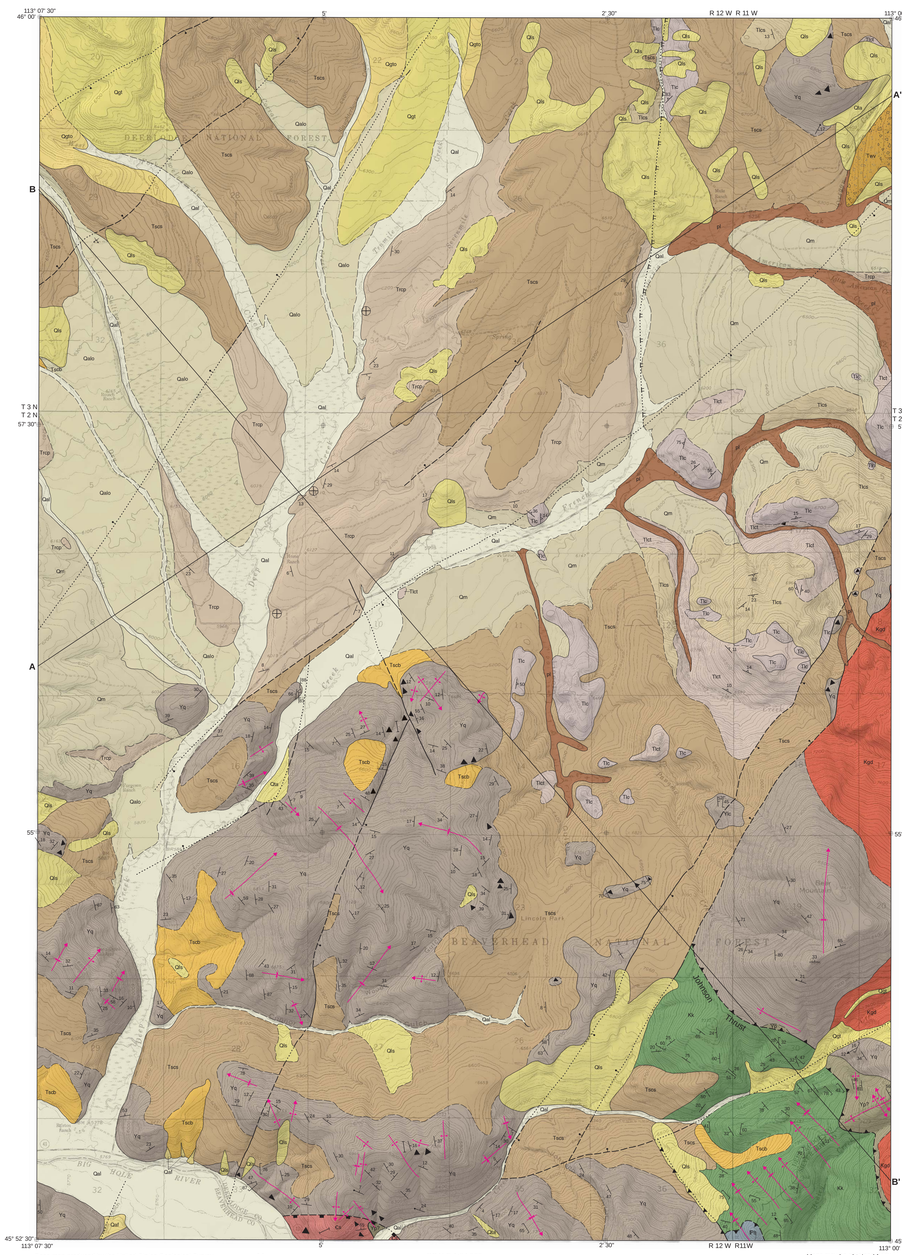
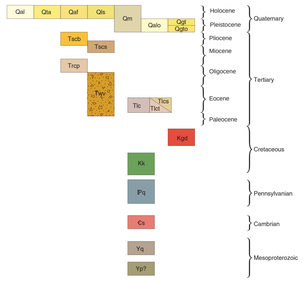
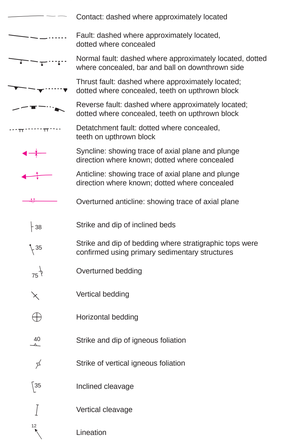


CORRELATION DIAGRAM



MAP SYMBOLS



INTRODUCTION AND BACKGROUND

The Lincoln Gulch 7.5' quadrangle is in the northeast corner of the Wisdom 30' x 60' quadrangle and connects areas of recent STATEMAP mapping by the MBMG (fig. 1). This study continues detailed mapping in the hanging wall, or upper plate, of the Anaconda Detachment (fig. 1; Elliott and others, 2013; Elliott, 2015; Elliott and Lonn, in review; Elliott and Scarberry, in review). The two main goals are to investigate the Cenozoic geology of southwestern Montana and identify phases of extension that created the intermontane basins, and to reassess the stratigraphic position of Paleoproterozoic exposures.

PREVIOUS MAPPING

Lewis (1993) mapped the Lincoln Gulch 7.5' quadrangle at a scale of 1:24,000 before recognition of the Anaconda Metamorphic Core Complex (O'Neill and others, 2004). The Lincoln Gulch 7.5' quadrangle is included in the Dillon 1° x 2° quadrangle (Ruppel and others, 1993, 1:250,000 scale). Maps of adjacent areas include Butte South 30' x 60' (McDonald and others, 2012, 1:100,000 scale), Dickie Peak 7.5' (McDonald, 2011, 1:24,000 scale), the Philipsburg 30' x 60' (Lonn and others, 2003, 1:100,000 scale), Lower Seymour Gulch 7.5' (Elliott, 2015, 1:24,000 scale), and Dickie Hills 7.5' (Lonn and McDonald, 2004, 1:24,000 scale).

GEOLOGIC ADVANCES

Proterozoic Stratigraphy

Lewis (1993) initially mapped the Mesoproterozoic quartzite, conglomerate, and argillite (Yq) in the Lincoln Gulch quadrangle as part of the Missoula Group of the Belt Supergroup. The quartzites are now recognized as belonging to the Swauger and Lawson Creek Formations of the Lemhi Range in Idaho. The Swauger and Lawson Creek Formations are laterally equivalent to the Missoula Group according to detailed stratigraphic work by Burmester and others (2013), Lonn (2015), and Lonn and others (in review).

Carbonate-rich quartzite (Yp?) along the Johnson Thrust (southeast corner of quadrangle) and along Bear Creek (south border) is strongly deformed and difficult to place stratigraphically. It most closely resembles exposures in the footwall of the Anaconda Detachment of the middle Belt Piegan Group, which has no close equivalent in the Lemhi Range. Unless the carbonate is a yet-unrecognized interval of the Swauger or Lawson Creek Formations, it must be in fault contact with Yq.

Cenozoic Stratigraphy

Lewis (1993) mapped most of the surface sediments of the Lincoln Gulch quadrangle as Quaternary glacial deposits. Glaciation fed sediments into the northwest side of the map area, but there are no glacial valleys or cirques that could have contributed sediments to the flanks of Bear Mountain to the southeast. Detailed mapping in adjacent quadrangles reveals a pre-glacial stratigraphy quite distinct from Quaternary deposits (Elliott, 2015; Elliott and Scarberry, in review). Granitic cobbles and boulders dominate the glacial sediments but are absent in Tertiary deposits, which are dominated by well-rounded cobbles and boulders of Mesoproterozoic quartzite. Glacial sediments are within and downstream of glacial valleys that originate in cirques high up in the mountains. Tertiary sediments lie on ridges and along hillsides that show no evidence of glaciation.

Tertiary sediments and rocks in the Lincoln Gulch quadrangle are herein correlated with members of the Renova and Sixmile Creek Formations elsewhere in southwest Montana. Well-cemented lithic sandstone and conglomerate interbedded with ashy silts and clays (Trcp) have the same age, lithology, and stratigraphic position as the Cabbage Patch Member of the Renova Formation as described by Konizeski and Donohoe (1958) and more recent authors (summarized in Calede and Rasmussen, 2015). Roe (2010) established a zircon age of 29.6 Ma (Oligocene) for tuff along French Creek near the base of the Trcp that is exposed in this quadrangle. The zircon age is within the 18.8–30.0 Ma Arikareean North American Land Mammal age range of the Cabbage Patch Beds (Calede and Rasmussen, 2015).

The poorly sorted, clay-rich gravels that overlie the Cabbage Patch Beds in the Lincoln Gulch quadrangle (Tscs) were named "Grassy Mountain sediments" (Tgm) in the west-adjacent Lower Seymour Lake quadrangle and interpreted as Renova Group equivalents (Elliott, 2015). Stratigraphic relationships in the Lincoln Gulch quadrangle suggest that the gravels instead correlate with the Sweetwater Member of the Sixmile Creek Formation as described by Sears and Thomas (2007) and Lonn and others (2000). The gravels appear to be equivalent to the Flint Creek Beds of Portner (2005) and Portner and others (2011), and the base of Sequence IV of Hanneman (1989) and Hanneman and Wideman (1991). In the Lincoln Gulch quadrangle, Tscs lies unconformably atop Trcp, like its counterparts throughout Montana (Vuke and others, 2007).

The well-rounded cobble gravel (Tscb) associated with Tscs in the Lincoln Gulch and adjacent Lower Seymour Lake quadrangles appears to correlate with the Big Hole Member of the Sixmile Creek Formation (Sears and Thomas, 2007; Lonn and others, 2000), the Barnes Beds of Portner (2005) and Portner and others (2011), and upper Sequence IV of Hanneman and Wideman (1991).

The significance of the revised stratigraphic correlations is twofold. First, the uniformity of the Eocene to Miocene stratigraphic sequence throughout southwest Montana does not lend itself to Janecke's (1994) model of a regional Eocene rift zone passing through western Montana (Thomas, 1995; Sears and Ryan, 2003), because there is no break in distribution or lithology across the region. Second, the high altitude of Sixmile Creek Formation exposures and evidence of post-Sixmile Creek faulting shows that at least some present-day mountainous topography is Pliocene or younger and was developed after deposition of the Sixmile Creek Formation.

The West Valley breccia (Twv) is a widespread, syntectonic, sedimentary, and tectonic breccia named after the well-described West Valley "chaos" of O'Neill and others (2004) and O'Neill (2005). In the Lower Seymour Lake quadrangle, the West Valley breccia extends along the Anaconda Detachment throughout its mapped extent (Elliott, 2015). The significance of the small exposure of Twv in the northeast corner of the Lincoln Gulch quadrangle is unresolved.

Structure

The Johnson Thrust is a regionally significant Late Cretaceous structure first mapped by Moore (1956). In the southeast corner of the Lincoln Gulch quadrangle, it places Proterozoic (Yq and Yp?) over Cretaceous rocks (Kk). The Johnson Thrust is complicated by subsidiary strands that place the Pennsylvanian Quadrant Formation (IPq) over Cretaceous (Kk), and Middle Belt Piegan Group? (Yp?) carbonate rocks over the Upper Belt-equivalent quartzite (Yq). The Johnson thrust extends through the east-adjacent Dickie Peak (McDonald, 2011) and southeast-adjacent Wise River (Fraser and Waldrop, 1972) quadrangles. Ruppel and others (1981) and Ruppel and Lopez (1984) interpret the Johnson Thrust to be the leading edge of the Grasshopper thrust plate, one of the two major thrust sheets in southwest Montana. These authors include the footwall of the Johnson Thrust in the frontal fold and thrust zone of the southwest Montana Sevier Orogeny.

The Proterozoic through Cretaceous rocks in the hanging wall and footwall of the Johnson Thrust contain at least two generations of upright folds forming dome and basin interference patterns. Overprinting relationships suggest that the fold generations reflect a change from northeast–southwest to east–west, shortening during orogenesis.

Top-to-the-east–southeast extension on the Anaconda Detachment and related faults occurred between 53 Ma and 27 Ma (Grice, 2006; Foster and others, 2010) and was accompanied by extrusion of the Lowland Creek Volcanics (Tlc, Tlct, Tlcs) (53–48 Ma, Dudás and others, 2010; Foster and others, 2010; Scarberry and Smith, 2014).

The Paleogene Anaconda Detachment separates the lower plate of the Anaconda Metamorphic Core Complex from unmetamorphosed upper plate rocks and sediments. The detachment is not exposed at the surface in the Lincoln Gulch quadrangle, but at depths extends into the map area from the west-adjacent Lower Seymour Lake quadrangle (see cross-section). The exposure of West Valley Chaos (Twv) in the northeast corner of the quadrangle suggests that a segment of the detachment is exposed nearby, probably due to late block faulting.

Steep normal faults in the northwest corner of the quadrangle are parallel to and syntectonic with the Anaconda Detachment. The other steep faults in the quadrangle cut the youngest Tertiary sediments and therefore the Detachment. Northwest-side-down movement on the steep fault along French Creek (north-center of quadrangle) allowed preservation of a wedge of Cabbage Patch Member (Trcp) strata on the northwest side of the fault and erosion of the remainder before deposition of the middle Miocene Sixmile Creek Formation (Tscs). Reactivation of the same fault with southeast-side-down motion offset the Sixmile Creek Formation in Pliocene or later times.

DESCRIPTION OF MAP UNITS

Qal **Talus (Holocene–Pleistocene)**—Angular and subangular cobble- to boulder-size clasts at the base of steep valley walls or cliffs. Thickness probably less than 30 m (100 ft).

Qta **Alluvium (Holocene)**—Modern stream and floodplain deposits. Thickness as much as 40 m (130 ft).

Qaf **Alluvial fan deposits (Holocene–Pleistocene)**—Angular to subrounded, unsorted, cobble to boulder gravel fans. Thickness probably less than 10 m (33 ft).

Qls **Landslide deposits (Holocene–Pleistocene)**—Unstratified, unsorted mixtures of sediment deposited by mass wasting. Color, composition, and grain size reflect the parent rock and transported surficial material. Thickness probably less than 60 m (200 ft).

Qm **Mantle (Quaternary)**—Structureless pebble and cobble lag over Tertiary sediments. Thickness less than 3 m (10 ft).

Qaslo **Older Alluvium (Pleistocene)**—Moderately to well-sorted, subrounded to well-rounded gravel and sand sheets immediately downslope from glacial deposits. Deposits are typically incised by younger alluvium. Thickness up to 45 m (150 ft).

Qgt **Glacial till (Pleistocene)**—Unsorted clay to boulder deposits in lateral, ground, and medial moraines. Characterized by hummocky terrain scattered with large subangular to subrounded granite boulders. Thickness may be as much as 120 m (400 ft).

Qgto **Glacial till, older than Qgt (Pleistocene)**—Unsorted clay to boulder deposits in lateral, ground, and medial moraines. Deposit surfaces are more subdued than Qgt, and granite boulders are smaller and more rounded. Thickness may be as much as 120 m (400 ft).

Tscb **Sixmile Creek Formation, Big Hole Member (Miocene)**—Boulder and cobble gravel dominated by rounded to well-rounded quartzite clasts. Clasts poorly to moderately sorted up to 40 cm (16 in) across. Mostly expressed as a lag deposit. Mapped as Tal in the west-adjacent Lower Seymour Lake quadrangle (Elliott, 2015). Equivalent to Tf and Ts of Hanneman (1984), who reports the presence of late Miocene vertebrate fossils. Thickness less than 65 m (220 ft).

Tscs **Sixmile Creek Formation, Sweetwater Member (Miocene)**—Gravel, sand, silt, and clay; typically red, though gray and tan beds occur, as well as some white tuffaceous beds. Unit is poorly exposed, but is characterized by popcorn-textured smectitic soils that are prone to landslides. Gravel is unsorted, with angular to well-rounded pebbles, cobbles, and boulders of Mesoproterozoic quartzites and argillites, granite myrlonite, and metamorphic rocks from the footwall of the Anaconda Detachment. Mostly matrix-supported debris flow deposits, but clast supported fluvial intervals exist. Mapped as Tgm in the west-adjacent Lower Seymour Lake quadrangle (Elliott, 2015). Thickness up to about 120 m (400 ft) within the Lincoln Gulch quadrangle.

Trcp **Renova Formation, Cabbage Patch Member (middle Oligocene to early Miocene)**—Pale colored, poorly- to non-lithified clays, silts, and tuffs, with well-lithified channelized sandstone and conglomerate. Detrital and life-position carbonized wood scattered throughout. Clays are commonly tuffaceous with pervasive yellow and orange mottling and blocky fracture. Silicified mudstone, sandstone, and conglomerate are brown to orange, coarse, lithic, feldspathic, and contain single large euhedral flakes of biotite and muscovite. Sandstone and conglomerate form trough cross-bedded lenses from less than a meter to more than 4 m thick. Pebbles and cobbles commonly imbricated. The coarse clastic lenses are most abundant at the top of the exposed unit and form steep banks along Deep Creek. Cross-bedded lenses of well-lithified lithic sandstone and conglomerate with euhedral feldspar, biotite, and muscovite grains are a distinctive feature of the Cabbage Patch beds across an area stretching from more than 100 km (60 mi) north of the Lincoln Gulch quadrangle (Calede and Rasmussen, 2015) to at least 140 km (85 mi) south (Elliott and Lonn, 2016). Trcp fills a northeast-trending pre-Sixmile Creek (Miocene) graben in the northwest half of the quadrangle, but is missing in the southeast where Tscs lies directly on bedrock. Roe (2010) obtained a zircon age of 29.6 Ma (Oligocene) for tuff along French Creek in the center of the quadrangle. Thickness reaches about 460 m (1,500 ft).

Twv **West Valley breccia (Oligocene–Eocene)**—Sedimentary and tectonic breccia characterized by large quartzite and carbonate blocks in an unsorted clastic matrix. Clasts include Proterozoic Swauger quartzite, Cambrian Flathead Formation quartzite, Hasmark Formation dolomite, dense black hornfels resembling Cretaceous Elkhorn Mountains Volcanics, caramel-colored chert, and gray rhyolite. Large blocks are brecciated and cemented with red and brown cryptocrystalline quartz. Twv is a mélange of tectonic and sedimentary breccias that extends along the Anaconda Detachment from the northwest end of the Deer Lodge Valley into the Big Hole Valley. In the Lincoln Gulch quadrangle, Twv is exposed only in the northeast but is inferred to underlie the northern third, where it extends from the adjacent Lower Seymour Lake 7.5' quadrangle (Elliott, 2015). In the Lower Seymour Lake quadrangle, it forms a 400- to 600-m-thick (1,300–2,000 ft) layer between two strands of the Anaconda Detachment.

Tlc **Lowland Creek Volcanics (early Eocene)**—Suite of flows, tuffs, and plugs at the southern end of a volcanic belt that is over 80 km (50 mi) long. Dated at 48–53 Ma (Dudás and others, 2010; Scarberry and Smith, 2014). In the Lincoln gulch quadrangle, they are dark gray to red aphanitic dacite with phenocrysts of quartz, biotite, and sanidine. Locally flow banded or scoriaceous. Poorly exposed light gray rhyodacite.

Tlcs Sedimentary facies of the Lowland Creek Volcanics. Includes green-cemented lahar deposits with clasts of red and caramel-colored chert; coarse crystalline marble; hornblende aplite; red, pink and green quartzite; fine-grained limestone, hornblende granodiorite; and volcanic lithologies. Expressed mainly as gravel lag in tuffaceous soils.

Tlct Light gray to white, variably welded, quartz–biotite–muscovite–feldspar crystal tuff.

Kgd **Granodiorite of Dodgson Creek Pluton (Late Cretaceous)**—Mostly medium gray and medium grained, slightly porphyritic granodiorite and tonalite (Lewis, 1993). A sample from the adjacent Wise River quadrangle yielded a biotite K-Ar date of 76.4 ± 2.6 Ma (Marvin and others, 1983).

Kk **Kootenai Formation (Early Cretaceous)**—Folded and foliated slate, metasandstone, and metaconglomerate with blobs and layers of marble. Meta-clastic rocks are shades of gray and green with maroon and black lenses. Relict fossils in the marble identify it as the gastropod limestone that regionally sits at the top of the Kootenai Formation. Lewis (1993) mapped parts of the exposure as Blackleaf Formation, but all rock types present are common in the Kootenai Formation. Thickness not determined.

IPq **Quadrant Formation (Pennsylvanian)**—Brecciated light gray, fine- to medium-grained, vitreous quartzite. Weathers light yellow brown to pale reddish brown, forms isolated knob in southeast corner of quadrangle where it is surrounded by the much younger Kk. Thickness not determined.

Cs **Metasediment (Cambrian?)**—Description based on-south adjacent Dickie Hills 7.5' quadrangle map (Lonn and McDonald, 2004): purple to light gray, fine- to medium-grained quartzite with sparse floating pebbles of quartz, interbedded with fine- to coarse-grained feldspathic quartzite with mud chips, trough and planar crossbeds, and flat laminations. The fine-grained quartzite has a flinty fracture and is micaceous and strongly foliated. Some of the feldspathic quartzite contains granules and pebbles of quartz and quartzite. Contains 1–27 percent feldspar, which is primarily potassium feldspar. Appears to be in depositional contact with the Cambrian Silver Hill Formation on the adjacent Dickie Peak and Wise River quadrangles. Thickness unknown.

Yq **Quartzites of the Lawson Creek and Swauger Formations (Mesoproterozoic)**—Maroon, gray, and dark pink to red feldspathic quartzite, conglomerate, and argillite. Poorly to moderately sorted, fine- to coarse-grained, with trough and planar crossbeds that are typically highlighted by black and red laminae. The Lawson Creek Formation has dark laminae and abundant mud rip-up clasts in fine- to medium-grained and moderately sorted quartzite. Feldspar grains are visible with a hand lens. Maroon argillite forms millimeter-thick layers. In the southern Big Hole Valley the Lawson Creek Formation is estimated to be over 2,000 m (6,500 ft) thick (Lonn and others, in review). The Swauger Formation is composed of well-rounded quartz, rounded to angular feldspar grains, and scattered frosted pink granules. Locally contains red and black mud rip-up clasts. Chalky white feldspar grains are obvious in hand samples. Conglomerate composed of angular to rounded quartzite, feldspar, and red and black chert clasts from granule to cobble size. Exposed thickness 3,400 m (11,000 ft). In the southern Big Hole Valley, the Swauger Formation is estimated to be as much as 3,000 m (10,000 ft) thick (Lonn and others, in review).

Yp? **Piegan Group? (Mesoproterozoic)**—Dark grey calcareous argillite and quartzite that weathers to pale yellow brown. Irregular beds from 1–60 cm (0.4–24 in) thick have "molar tooth" gas release structures that are typical of the Piegan Group (Furniss and others, 1998). Locally has dark gray chert, small channels, and cross-bedding. Poorly exposed and highly deformed in the Lincoln Gulch quadrangle. Stratigraphic correlation is uncertain and thickness is unknown.

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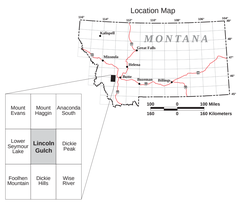

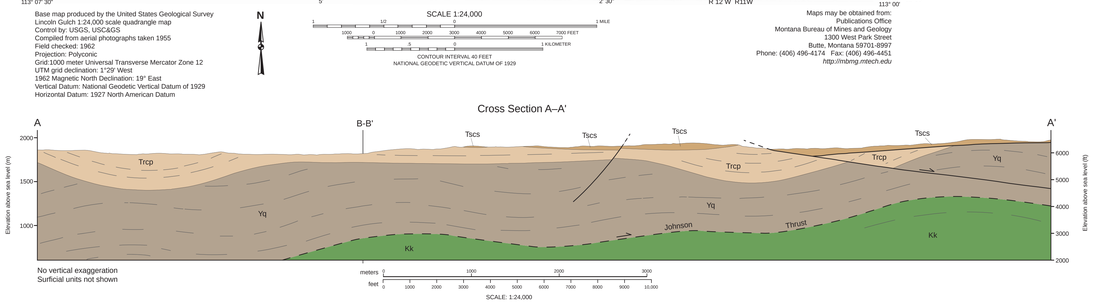

Base map produced by the United States Geological Survey
Lincoln Gulch 1:24,000 scale quadrangle map
Control by: USGS, USC&GS
Compiled from aerial photographs taken 1955
Field checked: 1962
Projection: Polyconic
Grid:1000 meter Universal Transverse Mercator Zone 12
UTM grid declination: 1°29' West
1962 Magnetic North Declination: 19° East
Vertical Datum: National Geodetic Vertical Datum of 1929
Horizontal Datum: 1927 North American Datum

Maps may be obtained from:
Publications Office
Montana Bureau of Mines and Geology
1300 West Park Street
Butte, Montana 59701-8997
Phone: (406) 496-4174 Fax: (406) 496-4451
http://mbmg.mtech.edu

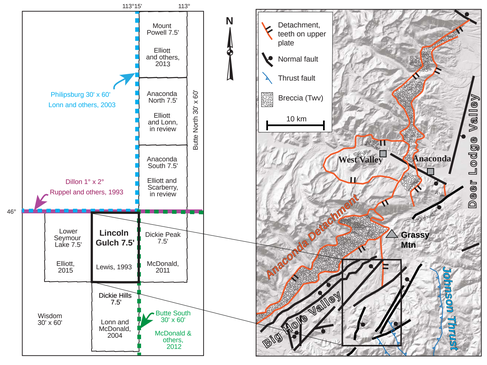

Figure 1. Previous mapping and regional structures.

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GIS production: Yiwen Li and Paul Thale, MBMG. Map layout: Susan Smith, MBMG. Edited by Susan Barth, MBMG.

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Geologic Map 70

Geologic Map of the Lincoln Gulch 7.5' Quadrangle, Southwestern Montana

Colleen G. Elliott

2017