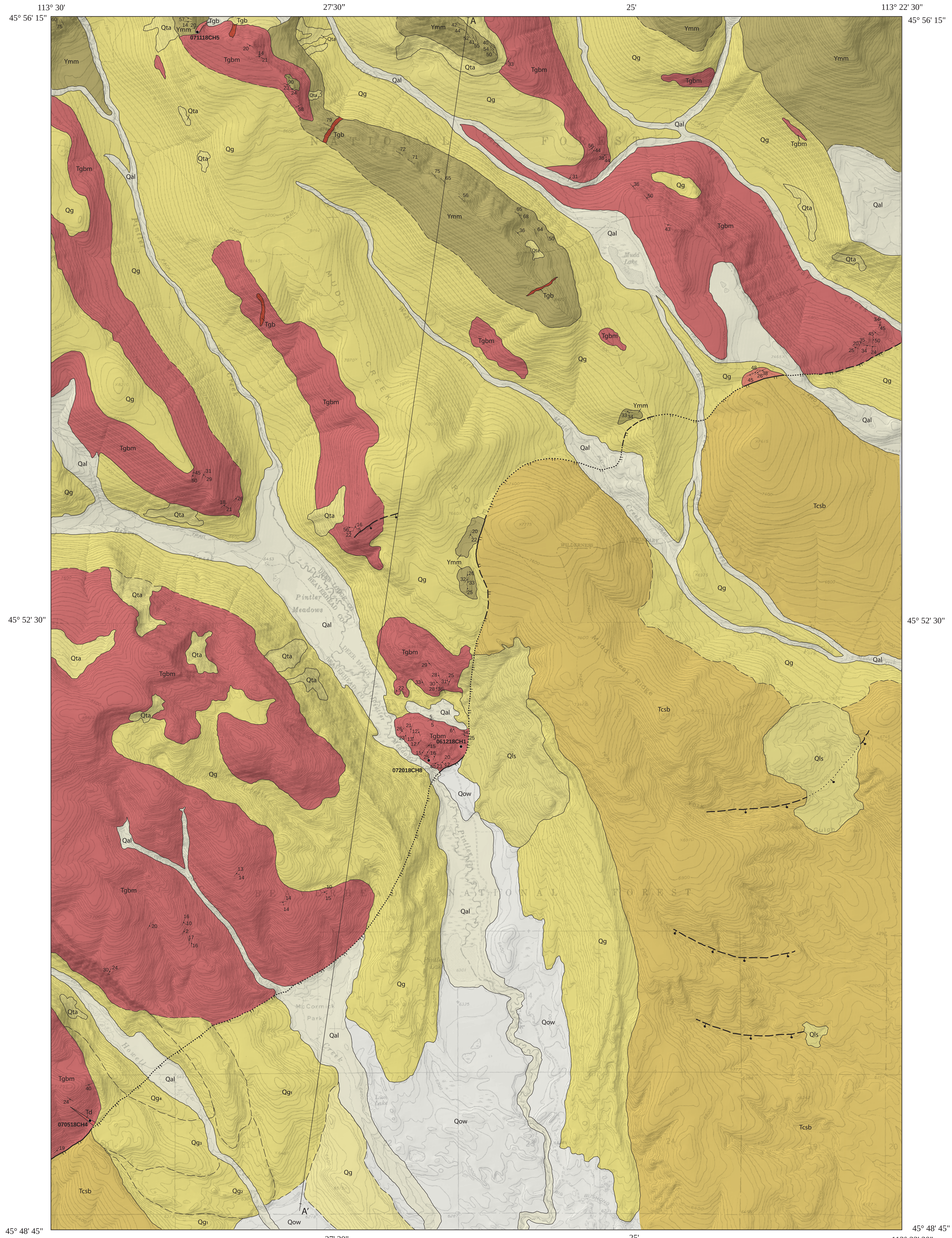


Base maps produced by the United States Geological Survey Pintler Lake & Warren Peak 1:24,000 scale quadrangle maps
Control by: USGS, NOS/NOAA and USFS
Compiled from aerial photographs taken 1955
Field checked: 1962
Projection: Polyconic
Grid:1000 meter Universal Transverse Mercator Zone 12
UTM grid declination: 1°40' West
1962 Magnetic North Declination: 19° East
2019 Magnetic North Declination: 12.78° East
Vertical Datum: National Geodetic Vertical Datum of 1929
Horizontal Datum: 1927 North American Datum

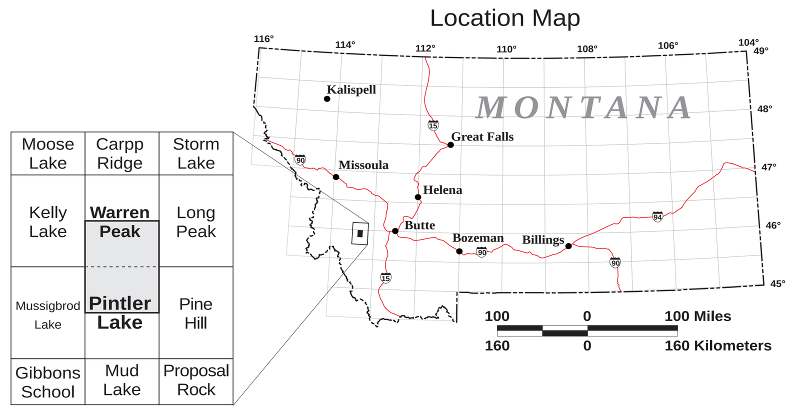
Shaded relief created from 3 meter digital elevation model from U.S. Geological Survey National Elevation Dataset.

SCALE 1:24,000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

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

Location Map



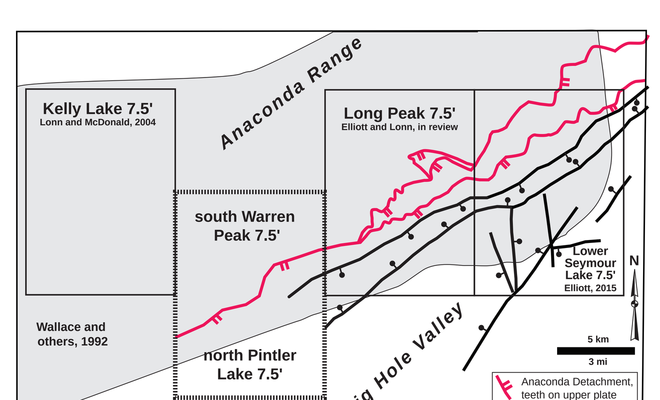
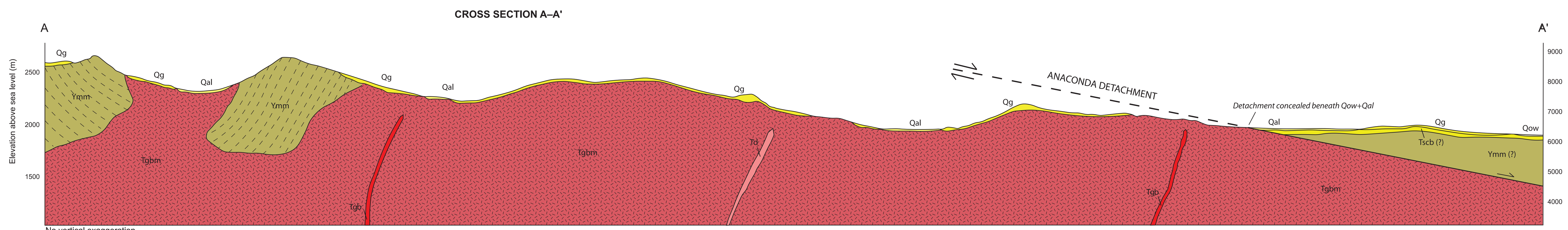


Figure 1. Previous mapping and location of major faults.

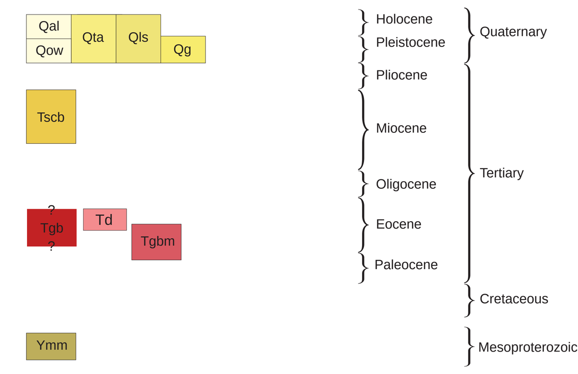
CROSS SECTION A–A'



SCALE: 1:24,000

Research supported by the U.S. Geological Survey EDMAP Program, under EDMAP award number G18AC00143.
GIS production and map layout: Caden J. Howlett, Montana State University.
This map sheet underwent full MBMG review by Colleen Elliott, Katie McDonald, Jesse Molsolf, and Jeff Lonn.

CORRELATION DIAGRAM



MAP SYMBOLS

Contact: dashed where approximately located

Normal fault: dashed where approximately located, dotted where concealed, bar and ball on downthrown side

Detachment fault: dashed where approximately located; dotted where concealed, teeth on upthrown block

Vertical bedding—showing strike

Inclined bedding—Showing strike and dip

Inclined bedding, where top direction is known from local features—Showing strike and dip

Strike and dip of foliation in Tgbm

Slickenline, groove, or striation on fault surface —Showing bearing and plunge

Geochronology sample location (ex. 061218CH1)

INTRODUCTION AND BACKGROUND

The Anaconda Metamorphic Core Complex (AMCC) is the easternmost in a group of Cordilleran metamorphic core complexes that formed during Eocene time (Constenius, 1996; Foster and others, 2010).

This project involved mapping two continuous half 7.5' quadrangles at 1:24,000 scale across the low-angle Anaconda detachment, in the Anaconda Range, ~50 mi WSW of Butte, Montana. The mapping included the north half of the Pintler Lake 7.5' quadrangle and the south half of the Warren Peak 7.5' quadrangle, in the northeastern part of the Wisdom 30' x 60' quadrangle. This mapping connects areas of recent STATEMAP mapping by the MBMG (fig. 1), and continues detailed mapping along the Anaconda Detachment Fault (Elliott and others, 2013; Elliott, 2015; Elliott, 2017; Elliott and Lonn, in review).

SIGNIFICANCE

The poorly understood influence of magmatism on metamorphic core complex formation justifies detailed study of deeply exhumed core complexes in the North American Cordillera. The AMCC is the least-studied core complex in the U.S. Cordillera, first documented in O'Neill and others (2004), and exhumes metamorphosed Tertiary plutonic rocks and Mesoproterozoic–Phanerozoic metasedimentary rocks from depths of ~12 km (Foster and others, 2010). Located within the Idaho–Montana segment of the Cordilleran Magmatic Arc, the AMCC may be a good example of a core complex whose development was driven by magmatism that created a hot, weak, and over-thickened crust.

PREVIOUS MAPPING (Fig. 1)

The adjacent Warren Peak and Pintler Lake 7.5' quadrangles are included in the Dillon 1° x 2° quadrangle (Ruppel and others, 1993, 1:250,000 scale), and the Anaconda–Pintler wilderness area (Wallace and others, 1992, 1:50,000 scale) covers the entirety of the Warren Peak 7.5' quadrangle and northern half of the Pintler Lake 7.5' quadrangle. Maps of adjacent areas include Kelly Lake 7.5' (Lonn and McDonald, 2004, 1:24,000 scale), Long Peak 7.5' (Elliott and Lonn, in review, 1:24,000 scale), and the Philipsburg 30' x 60' (Lonn and others, 2003, 1:100,000 scale).

METHODS (U-Pb Geochronology & Lu-Hf Analysis)

Five samples were collected from various granitic dikes and plutons within the AMCC footwall for zircon U-Pb geochronology. Two samples of the two-mica Pintler Creek Granite (Tgbm) were collected in the central map area (061218CH1, 072018CH8; 45.860°N, 113.445°W). Two samples were collected from a strongly foliated granodiorite dike (Tgb; 071118CH5) and dacite dike (Td; 070518CH4) that cross-cut the Pintler Granite at 45.935°N, 113.477°W and 45.824°N, 113.495°W, respectively. A fifth sample (071918CH7) was obtained from Td ~130 m north of the northern extent of the mapped area (43.939°N, 113.438°W).

Zircons were separated from ~1.5 L bulk samples by pulverization in a jaw crusher, sieving, magnetic separation, density separation, and hand-picking. Zircons were mounted in epoxy, polished to a depth of ~30 µm, and imaged using a backscattered-electron detector (BSE) with a cathodoluminescence attachment for targeting during analysis by laser-ablation inductively coupled plasma mass spectrometry (LA-ICPMS).

Zircon U-Pb ages were obtained for ~25 zircon grains per sample using a Photon Machines Analyte G2 Excimer laser attached to a Thermo Element2 HR single-collector ICP-MS at the University of Arizona Laserchron Center. Hf isotopic data were obtained for ~20 zircon grains from Tgbm sample 061218CH1 and the youngest sampled dike (071118CH5) using an identical laser ablation system attached to a Nu Plasma multicollector ICP-MS. Analysis and data reduction followed the detailed methods in Gehrels and Pecha (2014).

GEOLOGIC ADVANCES

The dominant structure in the map area is the Anaconda Detachment Fault. The detachment dips shallowly southeast (~12–15°), separating crystalline lower plate rocks from mostly unconsolidated Tertiary sediments in the upper plate. Crystalline lower plate rocks consist primarily of protomylonitic and undeformed two-mica granite, low greenschist facies metasedimentary rocks of the Belt Supergroup, and various dikes and sills of varying composition and age (fig.2a–d). Mylonitic shear zones associated with the Anaconda detachment are exposed in the central map area (45.860°N, 113.445°W) and are also shallowly dipping, with an average dip towards the west (fig. 3).

Zircon geochronology provides five new U-Pb ages from various granitoids and dikes in the AMCC footwall, and Lu-Hf isotopic analyses for two samples are presented (figs.4, 5). Comparison of new U-Pb ages to the Ar/Ar cooling ages produced by Foster and others (2010) provides insight into the relationship between magmatism and core complex exhumation. The relative timing of pluton emplacement in the Anaconda Core Complex indicates that it was primarily a cause of extension rather than a response (fig. 6). Comparison of the AMCC with other deeply exhumed northern Cordilleran complexes indicates variability in the timing and, therefore, relative influence of magmatism on the initiation of exhumation.

AMCC Footwall

Footwall rocks of the AMCC are made up of Late Cretaceous to Eocene granitic plutons that intruded into the metamorphosed Mesoproterozoic Belt Supergroup and Middle Cambrian to Cretaceous shelf-platform strata (Emmons and Calkins, 1913; Desmarais, 1983; Wallace and others, 1992; Lonn and others, 2003; Grice, 2006; Foster and others, 2010).

The crystalline footwall within this area of the AMCC is dominated by the Eocene two-mica granite known as the Pintler Creek Batholith (figs. 2a, 2b, 7, 8a, 8b) (Wallace and others, 1992). Two samples from the Pintler Creek granite (Tgbm) yielded new zircon U-Pb ages of 60.87 ± 0.59 Ma and 65.4 ± 3.9 Ma (fig. 4, 061218CH1, 072018CH8). The Pintler Creek granite intrudes deformed and metamorphosed rocks of the Belt Supergroup, and is cross-cut by a variety of deformed and undeformed granodiorite dikes (figs. 8c, 9). A strongly foliated granodiorite dike (Tgb) and a dacite dike (Td; fig. 8c) cross-cutting the Pintler granite yielded ages of 46.85 ± 0.22 Ma and 51.04 ± 0.25 Ma, respectively (fig. 4, 071118CH5, 070518CH4). Samples with mean square weighted deviations (MSWD) closer to 1.0 are better constrained than those with larger values. The high MSWD for the Tgbm samples is a result of slight variations in calculated crystallization ages.

Lu-Hf isotopic ratios, which provide insight into how isotopically evolved a melt was at the time of crystallization, were determined for samples 061218CH1 (n = 15) and 071118CH5 (n = 19). Presented in εHf space (more positive values represent melts that were more recently derived from a depleted mantle), values for 061218CH1 range from -18.5 to -28.1. εHf values for 071118CH5 vary from -5.3 to -15.3 (fig. 5). The pull-up in εHf space seen across these samples may represent increased mantle input during exhumation of the AMCC.

The Pintler Creek Batholith has a pervasive south–southeast dipping foliation with slip lineations that have a consistent trend to the southeast (figs. 3a, 3b, 10). The trend and plunge of slip lineations obtained from the Tgbm granite suggest unroofing was directed to the southeast, with an average plunge and trend of 19.0, 138° (fig. 3b). The best exposure of mylonitic rocks in the footwall of the Anaconda detachment is located at the southern end of Pintler Meadows (adjacent to geochronology samples 061218CH1 and 072018CH8). This approximately 1 km^2 region is host to anastomosing zones of high shear, two-mica granite, and gneiss (figs. 8a, 8b). Gneissic foliation, foliation in Tgbm, and shear zones predominately dip to the west. We interpret these west dips as a result of either back rotation from normal faulting that occurred after movement on the detachment had ended, or a second generation of slip along the Anaconda detachment, possibly consistent with a rolling-hinge kinematic model of detachment evolution. Foster and others (2010) concluded that extension on the detachment could have lasted until Oligocene times, and reported Ar/Ar thermochronology and apatite fission track data that establish movement from ca. 53 Ma to 27 Ma. If a second, more recent generation of slip on the Anaconda detachment is responsible for the west dipping gneissic foliation, it would potentially explain the variation in lineation trend and plunge observed in the field area and in adjacent quadrangles (e.g., Elliott and Lonn, in review).

AMCC Hanging Wall

The hanging wall of the Anaconda Core Complex is made up of Cenozoic–Quaternary clastic, volcaniclastic, and volcanic strata (Foster and others, 2010). In the Long Peak 7.5' quadrangle that is adjacent to the map area, Elliott and Lonn (in review) mapped the presence of 21.9 ± 0.3 Ma basalt flows (Fritz and others, 2007) that underlie the lowest member of the Six Mile Creek Formation (Sweetwater Member, Tscs). Overlying Tscs is the second and uppermost member of the Six Mile Creek Formation (Big Hole Member). The Big Hole Member of the Sixmile Creek Formation is the only Tertiary hanging wall unit identified in the map area, consisting of unconsolidated moderately sorted boulder to cobble quartzite clasts (fig. 11). Extensive glacial deposits likely cover any exposures of underlying Tertiary units.

Normal faults in the AMCC hanging wall are poorly exposed, and are here inferred from topographic lineaments exposed by digital elevation models. Faults were also identified by abrupt changes in float composition that can only be explained by rock unit juxtaposition. In places where the Anaconda detachment is covered by Quaternary sediments, there is usually an abrupt change from unconsolidated, well-rounded quartzite and granitic cobbles to mildly metamorphosed, foliated rocks on the AMCC footwall. It is possible that this abrupt change represents an area where the main detachment is cutting the Sixmile Formation. While it is possible that faulting ceased before Tertiary deposition and that sediments are draped across the faults, the coincidence between the topographic lineament and an abrupt change in surface float argues against it (Elliott and Lonn, in review).

Previous workers concluded that extension on the detachment ended in Oligocene times, and Foster and others (2010) used a variety of thermochronology data to establish movement from ca. 53 Ma to 27 Ma. If the Anaconda detachment truly offsets the Sixmile Creek Formation, movement along the detachment must have occured more recently.

DESCRIPTION OF MAP UNITS

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

Qow **Glacial outwash gravel deposits (Pleistocene)**—Unconsolidated deposits containing cobbles of all footwall rock types. Unknown thickness.

Qta **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).

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).

Qg **Glacial deposits (Pleistocene)**—Glacial deposits characterized by hummocky lateral, ground, and medial moraines scattered with large subangular to subrounded granite boulders, and composed of unsorted clay to boulder-size sediment. Thickness may be as much as 120 m (400 ft). Terminal moraines allow for the division of Qg into four distinct generations in the southwest corner of quadrangle (e.g., Qg_1, Qg_2, etc).

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, but locally imbricated. Correlated with the upper member of the Sixmile Creek Formation as described by Fritz and Sears (1993).

Tgb **Granite, monzogranite, and granodiorite, biotite (late Cretaceous and/or Paleogene)**—Generally porphyritic, non-foliated to weakly foliated. Similar to Tgbm, but distinguished by the absence of muscovite. Wallace and others (1992) include it in their Beaverhead Mountain stock, which intrudes Late Cretaceous thrust faults.

Td **Dacite and granodiorite porphyry (Eocene)**—Light to light tan porphyry dikes that vary in texture from granodiorite to dacite. Phenocrysts of plagioclase, quartz, and biotite are common. Quartz phenocrysts are commonly rounded. U-Pb ages range from 51.04 ± 0.25 Ma to 52.75 ± 0.61 Ma (fig. 4).

Tgbm **Pintler Creek granite and granodiorite, biotite–muscovite (Paleocene–Eocene)**—Fine- to medium-grain two-mica granite, dacite, and granodiorite of the Hearst Lake suite. Generally porphyritic, with matrix grain size ranging between fine and very coarse. Commonly associated with pegmatite and aplite dikes and sills. Mylonitic foliation is present within and adjacent to the Anaconda Detachment Fault. It appears to make up greater than three-quarters of the AMCC footwall in this quadrangle. Foster and others (2010) report $^{40}Ar/^{39}Ar$ cooling ages between 39 and 41 Ma for two-mica granite mylonites northeast of the quadrangle. Wallace and others (1992) include the Tgbm of Long Peak in their Pintlar (sic) Creek Batholith (Tpc) for which they got K-Ar ages ranging between 54 and 49 Ma. U-Pb ages from this quadrangle are 60.87 ± 0.59 Ma and 65.4 ± 3.9 Ma (fig. 4, this study).

Ymm **Mixed metasediments (Mesoproterozoic protolith, Cretaceous metamorphism)**—Interlayered quartzite, phyllite, and calc-silcate metasediments composed of decimeter- to meter-scale, planar layers of very fine-grained biotite quartzite and siltite separated by phyllitic skins. Some layers contain green calc-silicate minerals. These rocks appear to be gradational with and down section from thick-bedded quartzite of the Ravalli Group exposed on the north-adjacent Philipsburg 30' x 60' quadrangle (Lonn and others, 2003) in a large-scale north-dipping homocline. The presence of calc-silicate minerals and the thinner beds in comparison to the overlying Ravalli Group quartzite suggest that these rocks are the metamorphic equivalent to the Ravalli Group–Prichard Formation transition.

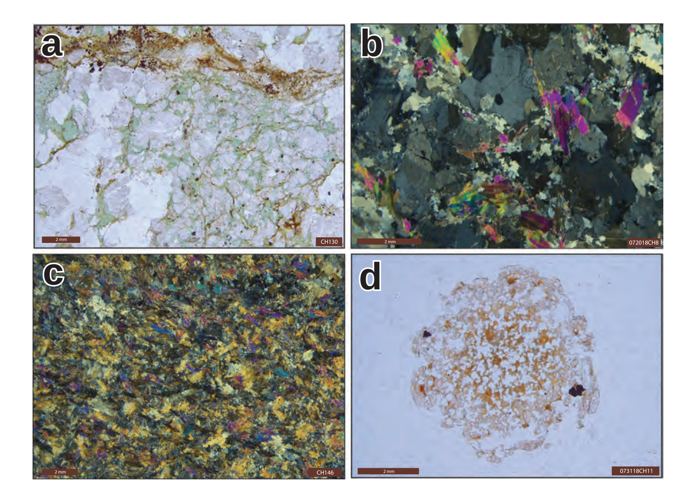
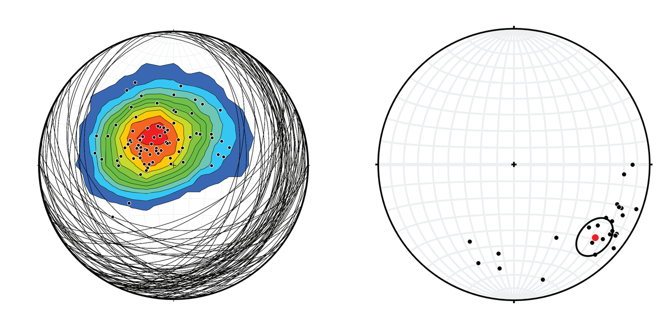


Figure 2. (a) Photomicrograph showing altered two-mica granite collected close to main detachment. Note abundant replacement chlorite. (b) Representative XPL photomicrograph of Pintler two-mica granite, the dominant AMCC footwall rock type. (c) Cross-polarized photomicrograph of meta-Belt (unit Ymm). (d) Poikiloblastic almandine garnet collected from leucogranite dike near central map area. All scale bars are 2 mm.



a. Foliation planes and poles to foliation n = 83 mean plane: 86°/27S

b. slip lineations n = 27 mean plunge and trend: 19.0-138°

Figure 3. Orientation data for the AMCC footwall. (a) Foliation planes. (b) Slip lineations and slickensides. Lambert equal area lower hemisphere projection.

U-Pb GEOCHRONOLOGY RESULTS

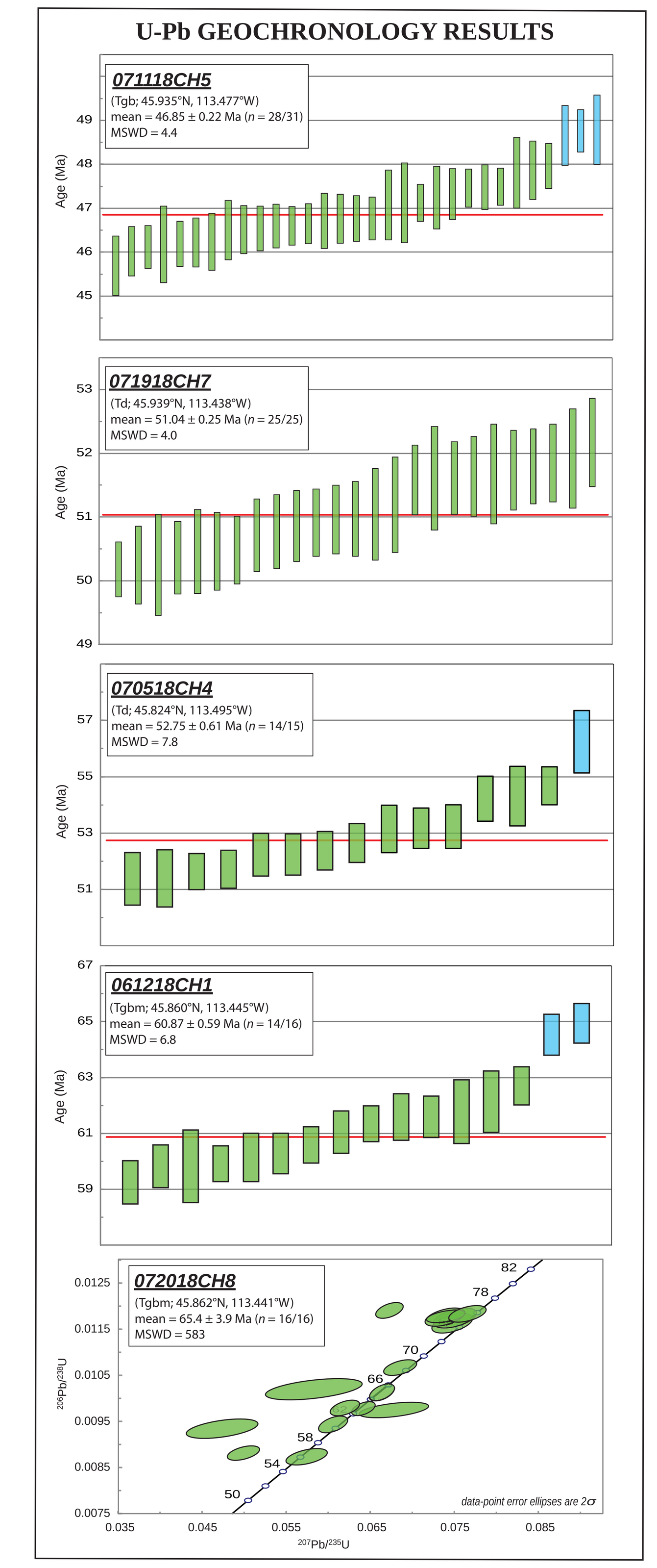


Figure 4. U-Pb zircon geochronology weighted mean plots from representative igneous rocks exposed in the AMCC footwall. Due to greater spread in U-Pb ages, sample 072018CH8 is displayed as a Wetherill concoria plot.Plots created using Isoplot4.15 Excel Add-in. Sample collection location is shown on map as solid black circle.

Lu-Hf RESULTS

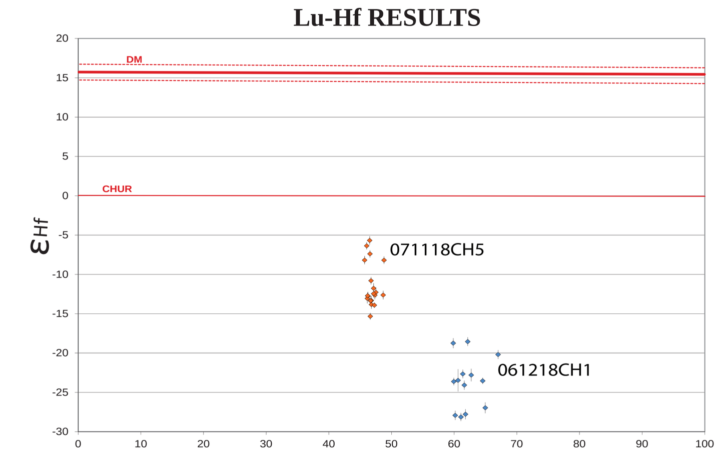


Figure 5. Epsilon plot displaying Lu-Hf results for 061218CH1 and 071118CH5. Both samples record negative epsilon values, suggesting moderately (CH5) to significantly (CH1) evolved melt derived from crustal sources. Red lines represent depleted mantle (DM) and CHUR evolution lines.

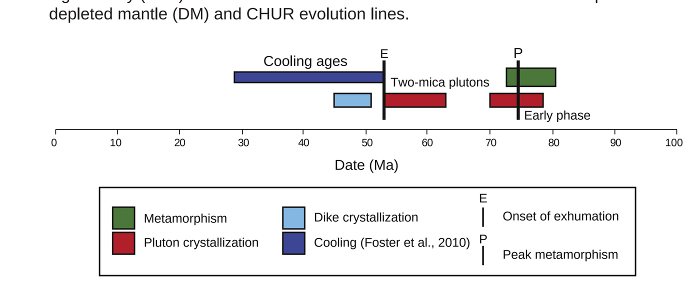


Figure 6. Comparison of the timing of metamorphism, magmatism, cooling, dike crystallization, and exhumation in the Anaconda Metamorphic Core Complex footwall. Figure adapted from Stevens and others, 2016. Data compiled from this study; Foster and others, 2010; Grice, 2006.

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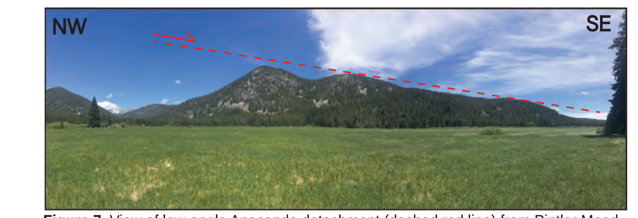

Figure 7. View of low-angle Anaconda detachment (dashed red line) from Pintler Meadows, central field area. Two-mica granite forms S/SE-dipping ridge. Ridge is approx. 2.5 km in length.

Figure 8. (a) Shear zone in Tgbm granite. Shear is top to the right, or top south-east. Compass for scale. (b) Orthogneiss outcrop within central map area. (c) Geochronology sample "070518CH4" that yielded a U-Pb age of 52.75 ± 0.61 Ma. Sample is from a medium- to fine-grained diorite dike with plagioclase phenocrysts. Dike cross-cuts the two-mica granite (Tgbm) of the AMCC footwall.

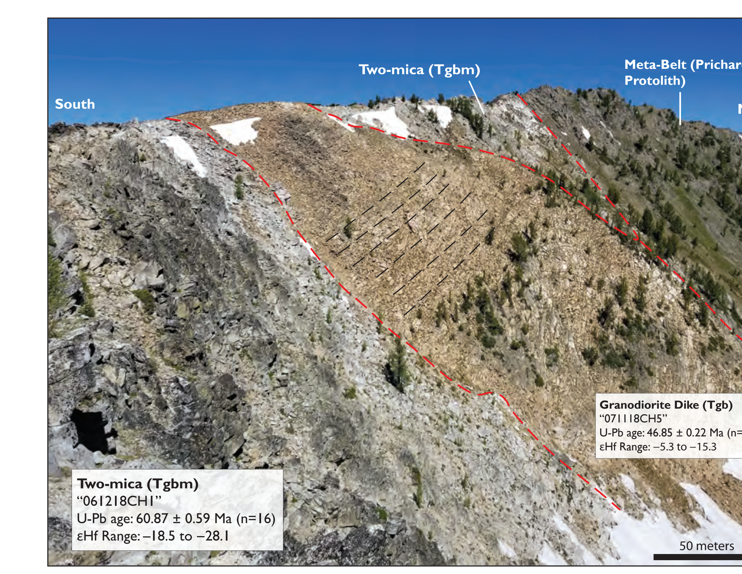

Figure 9. AMCC footwall exposing ~47 Ma granodiorite dike intruding between ~61 Ma two-mica granite and metasedimentary Belt rock. Dashed red lines are rock unit contacts and dashed black lines trace south-dipping foliation. The representative U-Pb ages and ranges of εHf values are included for each sample.

Figure 10. Foliated two-mica granite atop Continental Divide within AMCC footwall. Pen for scale with white arrow pointing in SE dip direction.

Figure 11. Hanging wall exposure along roadcut. Unconsolidated Sixmile Creek Formation. Notebook for scale.

MBMG
Montana Bureau of Mines and Geology

EDMAP 13

Geologic Map of the Northern Half of the Pintler Lake 7.5' Quadrangle and the Southern Half of the Warren Peak 7.5' Quadrangle, Southwestern Montana

Caden J. Howlett, Aislin N. Reynolds, and Andrew K. Laskowski
2020

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