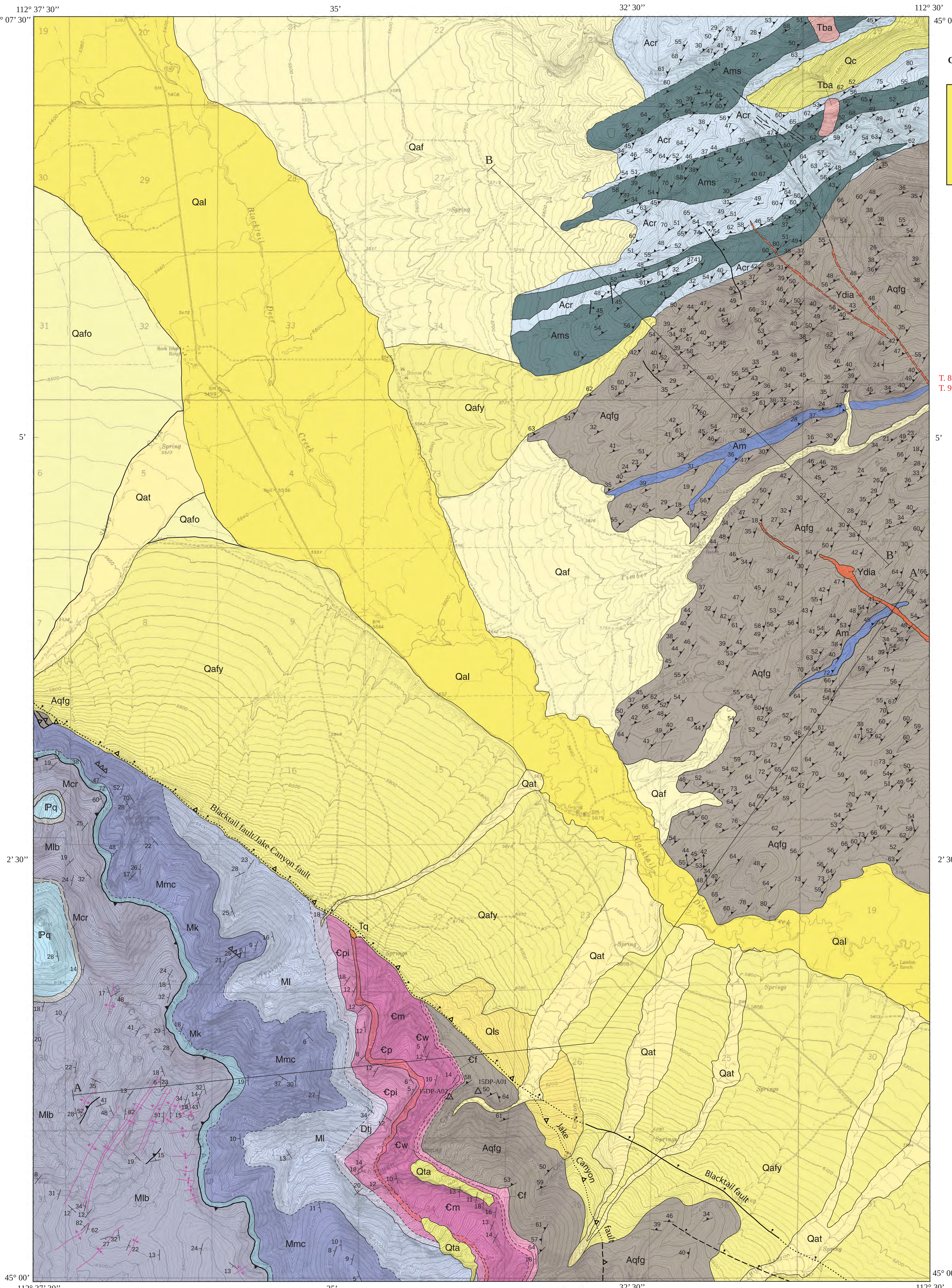
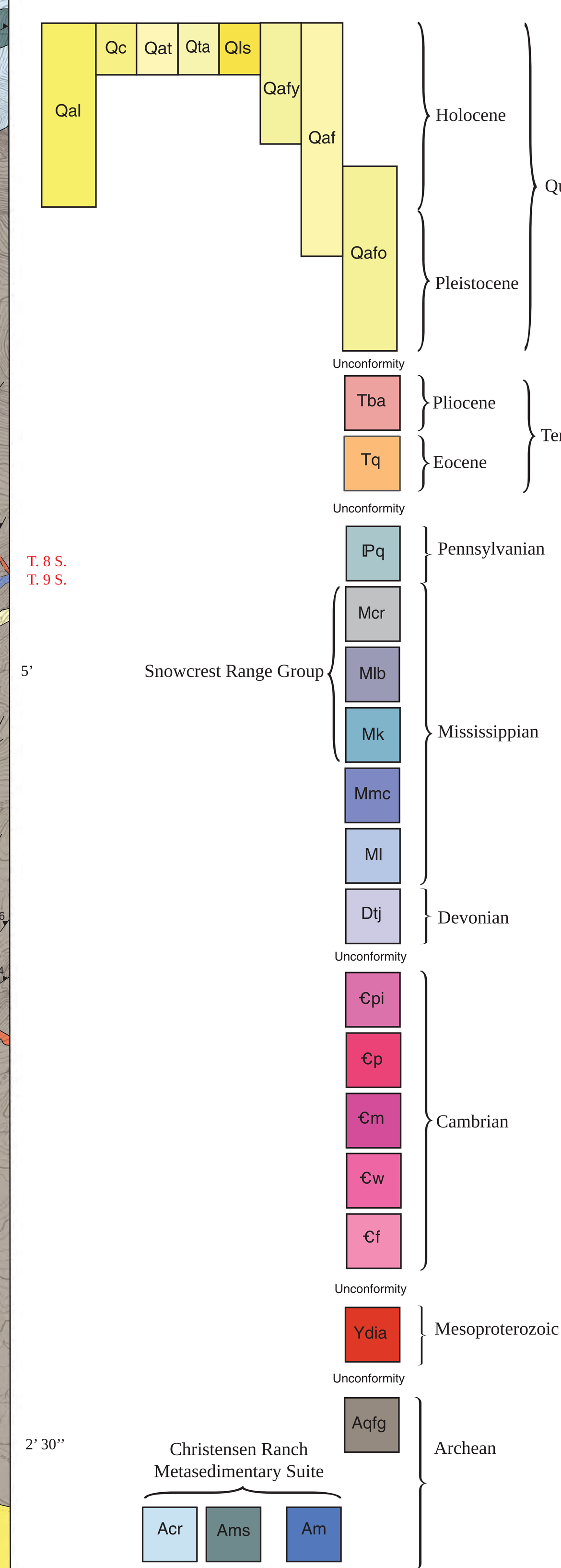
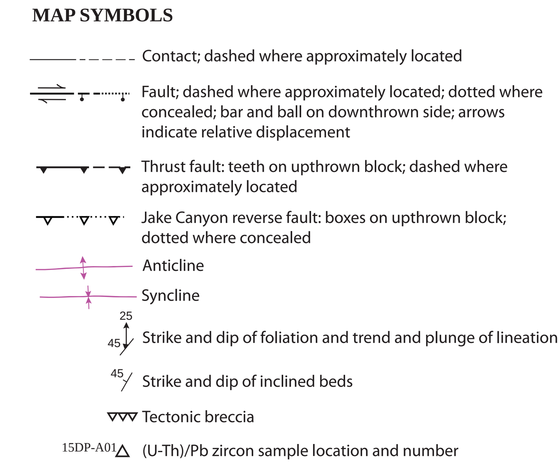


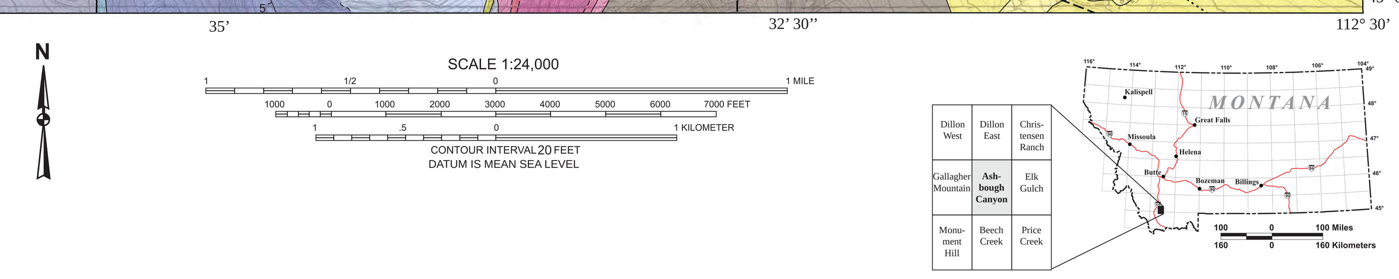
CORRELATION DIAGRAM



MAP SYMBOLS



Base from U.S. Geological Survey
Ashbough Canyon 7.5' topographic quadrangle
Map date: 1961
Projection: UTM zone 12; 1927 NAD
UTM grid declination 1°06' West
1961 Magnetic North Declination 18° East
Contour Interval 20 feet; Datum is Mean Sea Level



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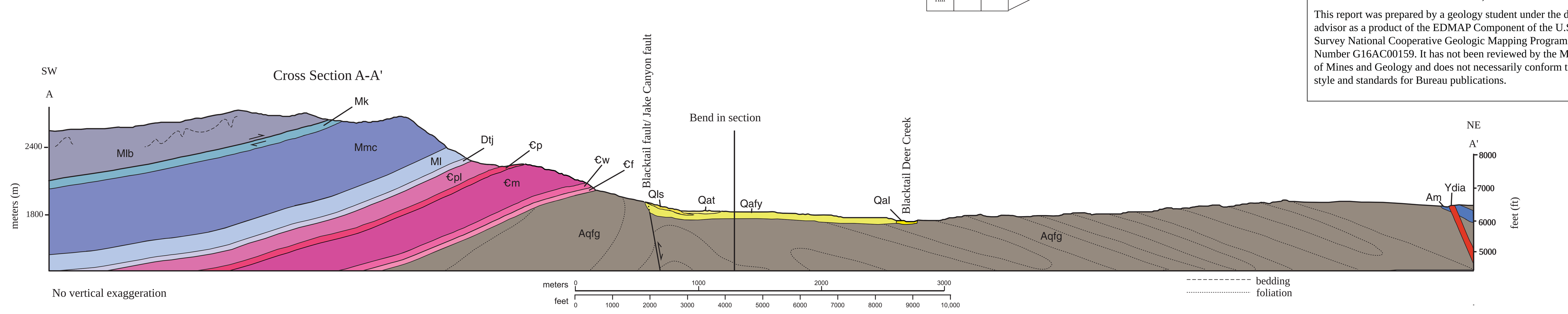
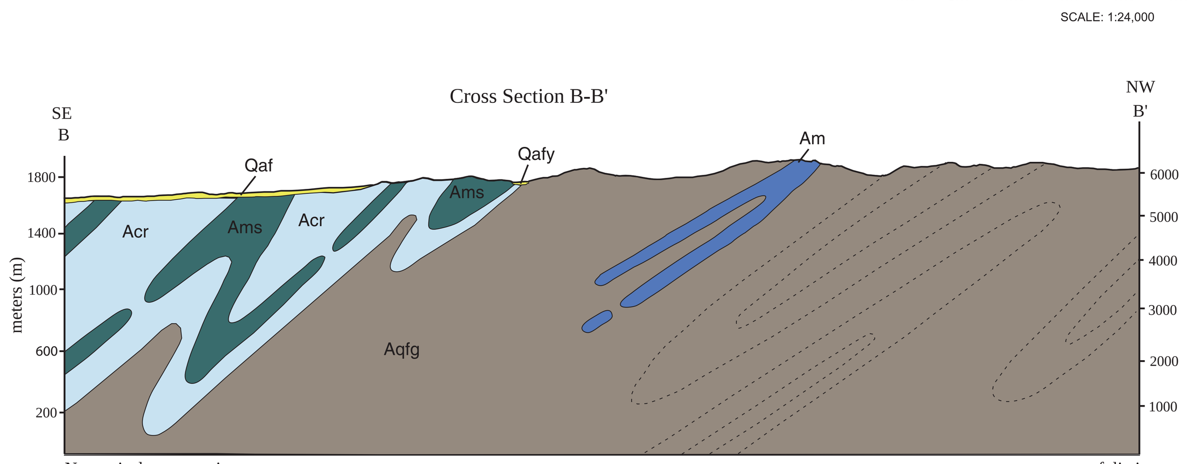
Montana Bureau of Mines and Geology
EDMAP 12, Plate 1

This report was prepared by a geology student under the direction of his advisor as a product of the EDMAP Component of the U.S. Geological Survey National Cooperative Geologic Mapping Program, Contract Number G16AC00159. It has not been reviewed by the Montana Bureau of Mines and Geology and does not necessarily conform to the usual style and standards for Bureau publications.

Cross Section A-A'



Cross Section B-B'



No vertical exaggeration
Scale is the same as Cross Section A-A'

Folds in basement for both cross-sections are drawn schematically; style and orientation are based on field observations

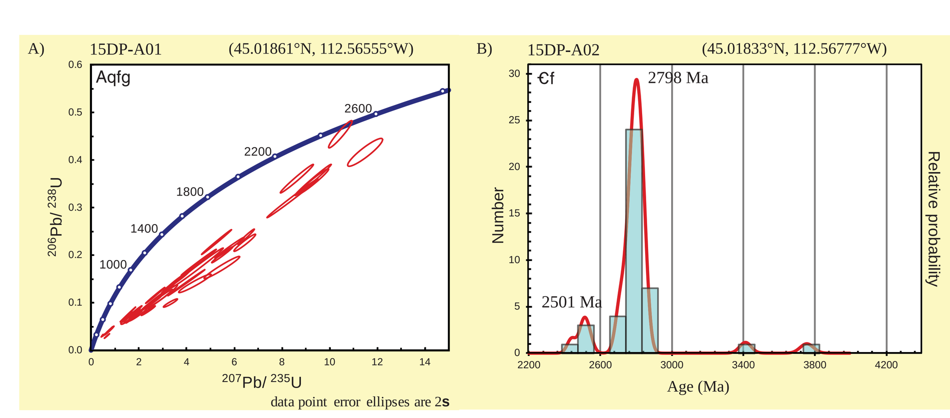


Figure 1. (U-Th)/Pb zircon data from the map area. A) (U-Th)/Pb zircon crystallization dates from the quartzofeldspathic gneiss (Aqfg; 15DP-A01) are highly discordant, which may indicate multiple lead loss events since initial crystallization. Discordant dates suggest the presence of an ~2700 Ma or older age population. Cramer (2014) and Jones (2008) documented a crystallization age of ~2770 Ma (or older) and a metamorphic age of ~2450 Ma from (U-Th)/Pb dating of zircons and monazites from the quartzofeldspathic gneiss elsewhere in the Ruby Range. B) (U-Th)/Pb dates of detrital zircons from a sample of the Flathead Formation (Ꞓf; 15DP-A02) directly above the nonconformity at Ashbough Canyon, do not display the regionally prevalent ~1780 Ma age-peak seen in other middle Cambrian units in the northern Rockies (May and others, 2013) and instead show two prominent age-peaks at ~2501 Ma and ~2798 Ma, which may suggest a local provenance.

INTRODUCTION

The Ashbough Canyon quadrangle was mapped during the summer of 2016 as a part of a M.S. thesis at Idaho State University. It was funded by the USGS EDMAP program (#G16AC00159).

GEOLOGIC SUMMARY

The oldest rocks exposed in the area are in the southern Ruby Range and central Blacktail Mountains and include ortho- and paragneisses of likely Archean age. The structurally deepest rocks are a quartzofeldspathic gneiss (Aqfg; the Dillon gneiss of Heinrich, 1960), with apparent screens of metasedimentary rocks (Am). (U-Th)/Pb zircon data from quartzofeldspathic gneisses at Ashbough Canyon and elsewhere in the Ruby Range suggest an intrusive age of ~2700 Ma or older, and the occurrence of a metamorphic event at ~2450 Ma referred to as the Tendoy orogeny (Jones, 2008; Cramer, 2015; this study) (fig. 1A). These quartzofeldspathic rocks are structurally overlain in the northwestern Ruby Range by paragneisses, schists, and marbles contained within the Christensen Ranch Metasedimentary Suite (Karasevich and others, 1981). Foliation data from the quartzofeldspathic gneiss (Aqfg) and the Christensen Ranch Metasedimentary Suite (Acr) are nearly identical and indicate that they were both likely metamorphosed and deformed during the Big Sky orogeny (fig. 2) (cf. Cramer, 2015). Isoclinal folds with foliation-parallel axial surfaces were identified at the outcrop-scale and used to infer the geometry of regional-scale folds.

In the central Blacktail Mountains, in the southwestern part of the map area, metamorphic rocks are overlain nonconformably by Middle Cambrian through Mississippian sedimentary rocks that dip gently to the northwest and west. Upper Mississippian rocks are intensely folded and deformed above the contact between the Kibbey Formation (Mk) and the Lombard Formation (Mlb). Prior mapping in the Lombard Formation (Mlb) showed many of these folded locations as thrust faults, meant to indicate the location of fault propagation folds related to Sevier-style shortening (Pecora, 1981; Tysdal, 1988a).

A Pliocene basalt is exposed in the northwestern Ruby Range and overlies the Christensen Ranch Metasedimentary Suite (Acr and Ams)(James, 1990).

Quaternary surficial deposits constitute a large portion of the map area. Three episodes of alluvial fan formation have been identified based on their stratigraphic relationship to other Quaternary units. The oldest alluvial fan (Qafo) occurs in the northwestern corner of the map and is heavily obscured, buried, and incised by all other Quaternary units. The two younger fan surfaces (Qaf and Qafy) were identified based on the gradients of their surfaces, the amount of stream incision (Qat), and the relationship with Blacktail Deer Creek. The oldest alluvial fan (Qafo) surface is incised by the Blacktail Deer Creek, which is the site of active deposition of alluvium (Qal). Quaternary fans (Qaf) contain material shed off the northeastern flank of the Blacktail Mountains. Active Quaternary terrace deposits (Qat) are formed on these fans and carry material to Blacktail Deer Creek.

Structure

The Ashbough Canyon quadrangle is located on the boundary between thin-skinned, Sevier-style thrusting and basement-involved, Laramide-style deformation (Schmidt and Garihan, 1983; Tysdal, 1988b). Prior work in the region recognized the northeast-dipping, Laramide-style Jake Canyon reverse fault (Pecora, 1981; Tysdal, 1988a), which places Archean quartzofeldspathic gneiss (Aqfg) over Paleozoic strata (Achuff, 1981).

Abundant folds deform the Mississippian Lombard Formation (Mlb). Stratigraphically lower Cambrian through Mississippian units did not accommodate major shortening, which indicates decoupling between structurally higher and lower levels. This is interpreted to indicate a décollement horizon at the base of the Lombard Formation (Mlb) related to the Sevier-style shortening in southwestern Montana. This décollement horizon was mapped as a thrust fault in the map area.

The northeast-dipping Jake Canyon reverse fault merges along-strike to the north into the northeast-dipping, normal-slip, Blacktail fault. This suggests that the Blacktail fault is likely a reactivated fault. The Blacktail fault occurs within the northern Basin and Range extensional province and was previously suggested to be active, with activity concentrated along the southeastern section of the fault (Stickney and Bartholomew, 1987; Stickney, 2007). Though largely buried beneath Quaternary sediments at the range front of the northern Blacktail Mountains, the fault cuts Quaternary sediments in the southeastern part of the map area, confirming Quaternary fault activity. Near the southern boundary of the map area, the Blacktail fault apparently accommodates slip along two or more splays that continue to the southeast along the front of the southern Blacktail Mountains (this study).

PREVIOUS MAPPING

Portions of the Ashbough Canyon quadrangle were mapped by Klepper (1950), Scholten and others (1955), and Okuma (1971). More recent mapping includes work on the gneisses in the Ruby Range by Garihan (1979), and Karasevich and others (1981), and in the Blacktail Mountains by Clark (1987). The Blacktail Mountains were mapped by Pecora (1981) (1:24,000) with a focus on the Mississippian stratigraphy, and by Tysdal (1988a) (1:24,000), who focused on the interaction between the Sevier and Laramide deformation in the region. The Paleozoic unit thicknesses within the Description of Map Units are taken from Tysdal (1988a) and mapping in the vicinity of Axes Canyon is modified from Okuma (1971) and James (1990). The most recent published map of the region is by Ruppel and others (1993), at 1:250,000-scale.

DESCRIPTION OF MAP UNITS

Qal **Alluvium (Holocene)—**Unconsolidated gravel, sand, silt, and clay in channels of modern rivers and streams. Clasts generally subrounded to well-rounded. Thickness varies but is generally less than 10 m (33 ft). Primarily deposited along the edges of the Blacktail Deer Creek. Alluvial surface is heavily obscured and has been buried by prograding alluvial fans originating from the Ruby Range and from younger alluvial terraces (Qat) in the Blacktail Mountains.

Qc **Colluvium (Holocene)**—Cobble to silt clasts and soils forming slumps adjacent to hillsides of unconsolidated material in the Ruby Range.

Qat **Alluvial-terrace deposit (Holocene)**—Boulders, gravels, pebbles, sand, and soils deposited adjacent to drainages that cut through Qaf and Qafy.

Qta **Talus deposit (Holocene)**—Boulder- to cobble-sized, angular blocks and debris. Occurs at the bases of cliff-forming Paleozoic units in the Blacktail Mountains.

Qls **Landslide deposit (Holocene)**—Mass wasting deposits of unconsolidated earthflow containing a mixture of Archean and Paleozoic units derived from the Blacktail Mountains. Identified on the basis of hummocky topography near the mouth of Ashbough Canyon.

Qafy **Alluvial-fan deposit, younger than Qaf (Holocene)**—Gravel, sand, silt, and clay with sparse boulders in fan-shaped deposits. Unconsolidated clasts and soils are derived from adjacent units in both the Blacktail Mountains and the Ruby Range. Youngest alluvial fan surfaces within the mapping area, which overlies both the older alluvial-fan deposits (Qafo) and the main northwest-southeast trending alluvial surface formed along the Blacktail Deer Creek (Qal).

Qaf **Alluvial-fan deposit (Holocene and Pleistocene?)**—Boulders, gravels, sands, and silt deposited in fan-shaped deposits. Loosely consolidated deposits formed from clasts derived from the Quartzofeldspathic Gneiss (Aqfg) in the Ruby Range, and clasts of the Archean through Paleozoic rocks in the Blacktail Mountains.

Qafo **Alluvial-fan, older than Qaf (Holocene and Pleistocene?)—**Unconsolidated gravel, sand, silt and clay deposited in low gradient fan in the northwestern portion of the mapping area. Material is heavily obscured as several ranches and farms have used this surface for agricultural purposes. Surface was identified due to its low elevation, and incision and burial by all other Quaternary units.

Tba **Basalt (Cenozoic: Pliocene)—**Red to black, porphyritic, basalt. Highly weathered to iron-stained red. Overlies Archean units in the Ruby Range in a roughly north-south oriented lava flow. Thickness is 15 m (49 ft).

Tq **Quartz (Cenozoic: Eocene)**—White-beige to red, quartz and jasperoid. Replaces quartzofeldpathic gneiss (Aqfg) adjacent to the Jake Canyon fault (Tysdal, 1988a).

IPq **Quadrant Formation (Pennsylvanian and Upper Mississippian)—**Tan to pale-yellow, fine-grained quartz sandstone. Some weathered surfaces have a red to light pink tint. Limited exposure on the southeastern edge of the map. The contact between the Quadrant Formation and underlying Conover Ranch Formation is sharp and conformable. Thickness is 210 m (690 ft).

Snowcrest Range Group (Pennsylvanian and Mississippian)—(Wardlaw and Pecora, 1985)

Mcr **Conover Ranch Formation (Upper Mississippian)—**Red to beige, very fine- to fine-grained, well to moderately-sorted quartz sandstone. Lower exposure of this unit is a matrix-supported conglomerate containing small pebbles of chert, limestone, and lithic fragments ranging from 0.3-4 cm. Unit forms poorly exposed outcrops on low gradient slopes. Lower contact is sharp and unconformable with the underlying Lombard Formation (Mlb). Thickness ranges from 6-9 m (20-30 ft).

Mlb **Lombard Formation (Mississippian)—**Upper yellow-tan to beige, fossiliferous, micritic limestone, and tan-beige, micritic limestone, with calcareous shale interbeds, thin- to thick-bedded, thickness 210 m (690 ft); and lower gray to tan-gray micritic limestone, medium-bedded to massive, thickness 140 m (500 ft). Upper part forms the cliffs and talus slopes adjacent to Mount Ashbough and contains flat, hardened, micritic layers, some up to 50 cm thick, with brachiopods and crinoids. Lower part locally forms cliffs with occasional fine to medium sand-sized fossil layers ranging from 1-4 cm thick, but in the southeastern portion of the map, the unit becomes very subdued and is exposed in limited locations within low grassy topography. The Lombard Formation is highly folded. The lower contact with the Kibbey Formation (Mk) is interpreted to be a décollement (i.e., bedding-parallel fault) horizon. Total thickness is at least 350 m (1025 ft).

Mk **Kibbey Formation (Mississippian)—**Tan to yellow, very-fine to fine-grained, well-sorted quartz sandstone, thin-bedded. Lower sandstone contains black chert grains. Exposure of unit is very limited in the field area. Contact is sharp and conformable with the underlying Mission Canyon Formation (Mmc). Thickness is ~30 m (100 ft).

Mmc **Mission Canyon Formation (Mississippian)—**Gray, micritic, fossiliferous limestone, with common red-beige chert nodules and ribbons, massive-bedded. Forms prominent cliffs throughout the field area. Contains fossil layers (2-8 cm thick) composed of rugosans and brachiopods. Localized calcite veins up to 50 cm wide can be found in the upper portion of the unit. Upper section also contains a brecciated layer composed primarily of crystalline limestone fragments with some minor quartz, supported by a tan/red clay rich calcitic matrix. The contact with the underlying Lodgepole Formation (Ml) is conformable and gradational. Was mapped at the occurence of brown to gray shale. Thickness ranges from 270 m (885 ft) to 340 m (1115 ft).

Ml **Lodgepole Formation (Mississippian)—**Gray-tan, fossiliferous limestone, thin- to medium-bedded, with interbedded gray, micritic to crystalline limestone, and thin-bedded, tan-beige calcareous siltstone. Commonly slope-forming and weathers to orange, black, and purple. Upper 35 m (115 ft) of unit has 1-5 mm thick lenses of brown to gray calcareous shale. Unit emits a fetid smell when broken. Fossils found throughout the unit are commonly in discrete layers (1-4 cm thick) and include crinoids (>1 mm), minor fusulinids, brachiopods (>2 mm), and rugosan corals. Contact with underlying Jefferson and Three Forks formations is not observed but is likely conformable. Thickness is 220 m (720 ft).

Dtj **Three Forks Formation and Jefferson Formation, undivided**—Poorly exposed in the map area. Total thickness is 54 m (180 ft).

Three Forks Formation (Lower Mississippian and Upper Devonian)—Gray-blue calcareous shale. Limited exposure in the field area, observed as float above cliffs of the Pilgrim and Jefferson formations. Contact with underlying Jefferson Formation is thought to be unconformable (Pecora, 1981).

Jefferson Formation (Upper Devonian)—Yellow-beige-red to gray-tan when weathered, sugary dolostone with interbeds of fine calcareous shale, fine- to medium-bedded. Forms small outcrops. Limited exposure near the mouth of Weston Canyon and on the southern boundary of Ashbough Canyon. Lower contact is not exposed but is thought to be unconformable with the underlying Pilgrim Formation (Ꞓpi) (Pecora, 1981).

Ꞓpi **Pilgrim Formation (Upper Cambrian)**—Gray to pink, fine- to medium-grained, sugary dolomite, medium- to thick-bedded. Forms large cliffs. Lower contact is concealed but is thought to be conformable with the underlying Park Formation (Ꞓp). Thickness is 60 m (200 ft).

Ꞓp **Park Formation (Middle Cambrian)**—Green-gray to gray-tan, argillaceous and micaceous shale, thin- to medium-bedded. Poorly exposed slope-former; observed as float between cliffs of the Meagher and Pilgrim formations. Contact with the underlying Meagher Formation (Ꞓm) is thought to be conformable. Thickness is 30 m (100 ft).

Ꞓm **Meagher Formation (Middle Cambrian)—**Orange to light-pink dolostone that is fine to medium crystalline, medium- to thick-bedded. Exhibits tan to red, mottled texture, oriented roughly perpendicular to bedding and interpreted to result from bioturbation (Thomas and Roberts, 2007). Forms prominent cliffs near Ashbough Canyon. The upper 17 m (56 ft) is orange to gray, and contains minor, gray to green, shale interbeds. Upper layers also display trough cross-beds. The underlying contact with the Wolsey Formation (Ꞓw) is not exposed but is thought to be conformable and gradational (Pecora, 1981). Thickness is 175 m (575 ft).

Ꞓw **Wolsey Formation (Middle Cambrian)—**Black, gray, and olive-green argillite and micaceous shale, with minor gray slate. Poorly exposed in the mapping area; observed as float between the Flathead Formation and the base of cliffs of Meagher Formation. Conformable contact with the underlying Flathead Formation. Thickness is 24 m (80 ft).

Ꞓf **Flathead Formation (Middle Cambrian)—**Upper light yellow to tan-gray, fine- to medium-grained, moderately to poorly sorted subarkose, arkose, and quartz arenite and quartzite about 9 m (30 ft) thick, and lower maroon to pink, fine- to coarse-grained arkosic sandstone and pebble conglomerate, with 1-5 mm sub-angular to angular quartz and feldspar clasts, medium-bedded, about 0.6 m thick (2 ft). Trough cross-bedding is present in the upper sections. Contact with underlying quartzofeldspathic gneiss (Aqfg) is sharp and nonconformable, with underlying gneisses dipping 35-40° to the northwest beneath the contact. Detrital zircons separated from basal sandstone indicate derivation from Archean sources (Fig. 1B). Thickness ranges from 6 m (20 ft) to 25 m (32 ft).

Ydia **Diabase (Mesoproterozoic?)**—Red-black, aphanitic, diabase dike. Forms a tabular, northwest-southeast striking body that intrudes quartzofeldspathic gneiss (Aqfg) and marble (Am) within the Ruby Range. Previous workers have suggested it was emplaced during a regional extensional event ~1.4 Ga (Wooden and others, 1978; James, 1990).

Aqfg **Quartzofeldspathic Gneiss (Archean)**—Includes various quartzofeldspathic gneisses as well as pegmatite, amphibolite, and diorite dikes and sills. Was originally mapped as the Dillon Granite Gneiss (Heinrich, 1960). However, later mapping suggested a sedimentary (Karasevich and others, 1981) or mixed igneous and sedimentary protolith (James, 1990). Recent work has suggested that this unit was initially a granitic intrusion that crystallized ~2700 Ma (Jones, 2008; Cramer, 2015; this study). Here, gneisses of predominantly quartzofeldspathic composition were mapped separately from apparent screens of marble and associated schist.

Hornblende-garnet-biotite-plagioclase-quartz-microcline gneiss: White-gray to red-pink, medium-grained, moderately foliated gneiss of granitic composition. Pb-Pb zircon crystallization and (U-Th)/Pb monazite metamorphic ages obtained by Jones (2008), Alcock and Muller (2012), Cramer (2015), and from this study (fig. 1A) indicate likely initial crystallization of the protolith of the orthogneiss at ~2.7 Ga, followed by multiple episodes of metamorphism at ~2.4-2.5 Ga (Tendoy orogeny) and 1.8-1.7 Ga (Big Sky orogeny).

Garnet-biotite-quartz-microcline gneiss: white-gray, fine-grained, moderately foliated gneiss. Lithology is commonly observed in the flat-lying areas of the Ruby Range, outcrops display northwest-trending isoclinal folds.

Biotite-quartz-plagioclase-microcline gneiss: White-gray to beige, medium- to coarse-grained, weakly foliated gneiss of granitic composition.

Quartz-microcline-garnet-biotite gneiss: black to red-black, medium- to coarse-grained, lightly to moderately foliated gneiss.

Sillimanite-quartz-plagioclase-biotite-microcline gneiss: White-brown to white-gray, fine- to medium-grained, moderately foliated gneiss.

Calcite-quartz-garnet-biotite-microcline schist: Dark gray to black, fine-grained schist. Exposed along the contact between the quartzofeldspathic gneiss (Aqfg) and dolomitic marble (Am).

Pegmatite: White to pink, quartz and potassium feldspar-rich veins intruding the other lithologies in the quartzofeldspathic gneiss. Intrudes the contact between the quartzofeldspathic gneiss (Aqfg) and the Christensen Ranch Metasedimentary Suite (Acr).

Amphibolite: Black, hornblende-rich, medium- to coarse-grained amphibolite. Exposed as sills within the quartzofeldspathic gneiss lithologies.

Diorite: Black to dark gray, composed of plagioclase, hornblende, and pyroxene. Dikes and sills intrude the various other lithologies in the Ruby Range.

Gabbro: Black, composed of pyroxene and plagioclase. Exposed as dikes and sills intruding various lithologies in the quartzofeldspathic gneiss, primarily in the Blacktail Mountains.

Christensen Ranch Metasedimentary Suite—(James, 1990)

Acr **Christensen Ranch Metasedimentary Rocks (Archean?)—**Includes metasedimentary gneisses and schists, as well as pegmatite, amphibolite, and diorite sills and dikes. Originally mapped as the Cherry Creek Group (Karasevich and others, 1981), but renamed by James (1990). One (U-Th)/Pb monazite date suggests that the unit was deposited prior to ~2553 Ma (Jones, 2008).

Quartz-plagioclase-microcline-sillimanite-biotite gneiss: Gray-tan to white, fine- to medium-grained, moderately foliated gneiss. The gneiss is interlayered with other metasedimentary lithologies found in the Christensen Ranch Metasedimentary Suite (Acr). Contact with the underlying quartzofeldspathic gneiss appears to be intrusive, however the contact is obscured by pegmatite and amphibolite sills.

Quartz-sillimanite-biotite-garnet schist: white-tan, fine-grained, aluminous schist.

Pegmatite: White-tan, coarse crystalline, quartz-rich pegmatite. Occurs as sills and dikes that intrude the gneisses, schists, and marble of the Christensen Ranch Metasedimentary Suite (Acr). Some outcrops contain large (1-3 cm thick) biotite books. Some pegmatite dikes display a foliation that is concordant with the regional northwest-dipping foliation, indicating they were intruded prior to or during deformation in the Big Sky orogeny (1.7-1.8 Ga) (Jones, 2008; Cramer, 2015).

Amphibolite: Black, medium- to coarse-grained, hornblende-rich amphibolite. Exposed as sills and dikes.

Diorite: Black, fine- to medium-grained diorite sills.

Ams **Christensen Ranch Marble (Archean?)—**White, white-tan, medium-to coarse-grained, calcitic marble. This marble is part of the Christensen Ranch Metasedimentary Suite (Acr), but was mapped separately (Karasevich and others, 1981).

Am **Marble (Archean?)**—Includes dolomitic marble and lesser garnet-chlorite-biotite-hornblende-quartz schist preserved as apparent screens within the quartzofeldspathic gneiss (Aqfg). These rocks may be equivalent to the Christensen Ranch Marble (Ams).

Dolomitic marble: White-tan, fine-to medium-grained recrystallized dolomitic marble. Contact with surrounding Aqfg unit is interpreted as intrusive based on occurrence of the marble as apparent screens within the surrounding quartzofeldspathic gneiss (Aqfg). May have the same protolith as Marble (Ams) that occurs within the Christensen Ranch Metasedimentary Suite on the northwestern side of the Ruby Range.

Garnet-chlorite-biotite-hornblende-quartz schist: Black to dark gray, fine-grained schist. Exposed adjacent to the dolomitic marble.

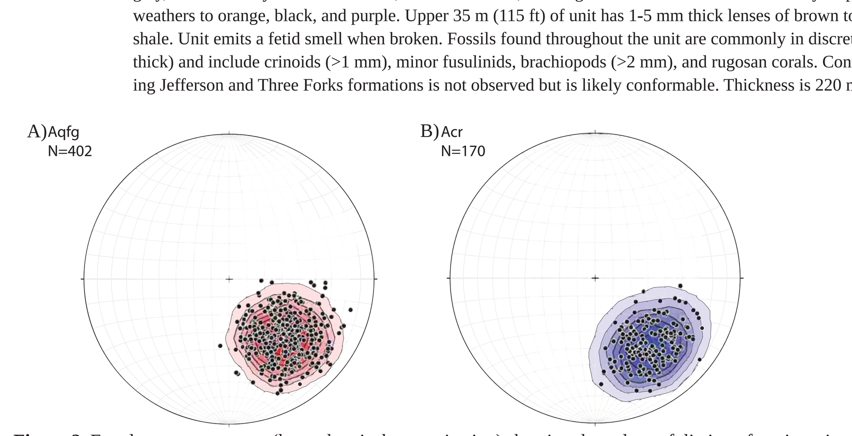


Figure 2. Equal area stereograms (lower-hemisphere projection) showing the poles to foliation of gneisses in the Ruby Range fit with Kamb contours. A) Poles to foliation in the quartzofeldspathic gneiss (Aqfg) define an average pole that plunges 41°, with a trend of 137°. B) Poles to foliation in the Christensen Ranch Metasedimentary Suite (Acr) define an average pole that plunges 37°, with a trend of 140°. These stereograms suggest that the Christensen Ranch Metasedimentary Suite (Acr) and quartzofeldspathic (Aqfg) gneisses have statistically indistinguishable foliation orientations and reflect one deformational event; the orientation and timing of deformation constrained for similar rocks to the north (Harms and others, 2004) suggests that all units in the Ruby Range were metamorphosed and deformed together during the ~1.78-1.72 Ma Big Sky orogeny.

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EDMAP 12

Geologic Map of the Ashbough Canyon 7.5' Quadrangle, Beaverhead County, Montana

Brandon M. Crawford and David M. Pearson
Idaho State University

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