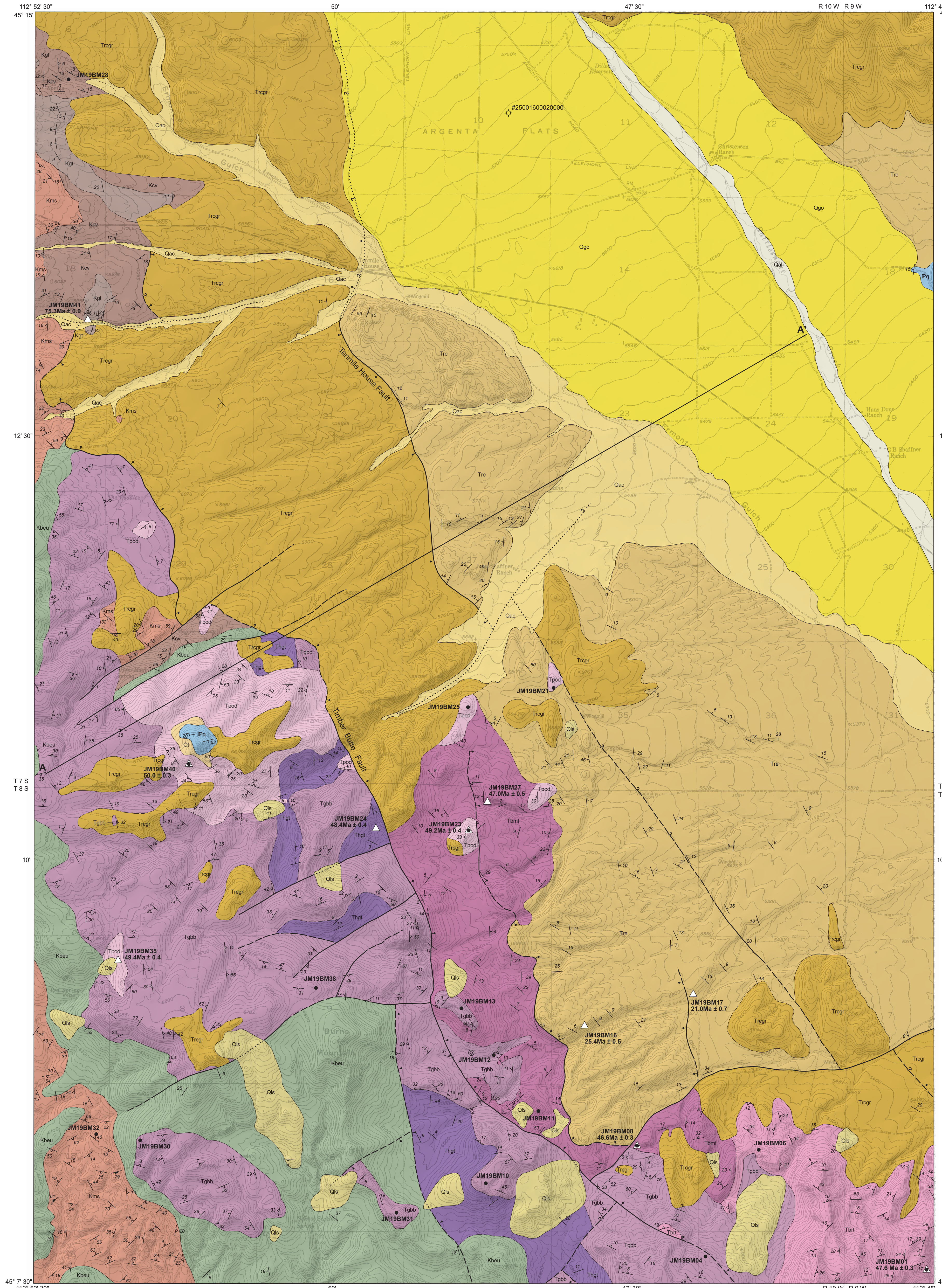


Burns Mountain 1:24,000-scale quadrangle map
Base map produced by the United States Geological Survey
Control by USGS and USC&GS
Topography from aerial photographs by multiplex methods and plane-table surveys 1952. Aerial photographs taken 1950.
Revisions compiled from aerial photographs taken 1978 and other source data. Not field checked. Map edited 1979
Projection: polyconic
Grid:1000 meter Universal Transverse Mercator Zone 12
Vertical Datum: National Geodetic Vertical Datum of 1929
Horizontal Datum: 1927 North American Datum

Shaded relief created from 10 meter digital elevation model from U.S. Geological Survey National Elevation Dataset.

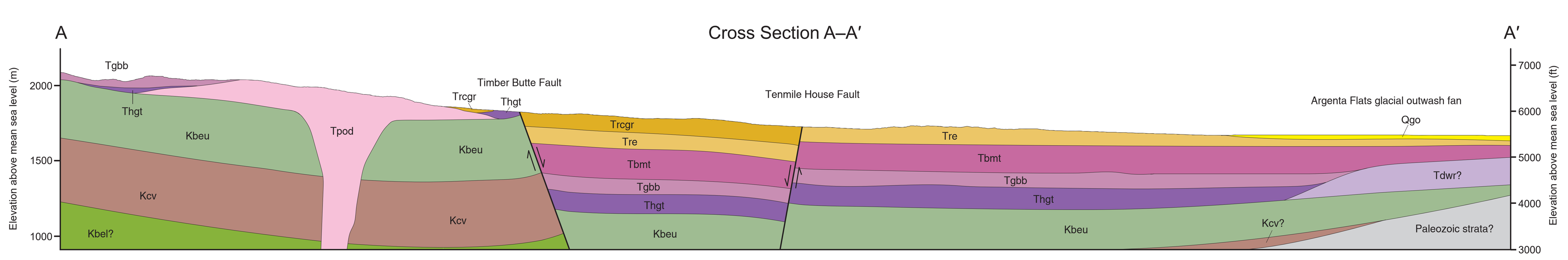
SCALE 1:24,000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

UTM GRID AND 2017 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

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
http://mbmg.mtech.edu

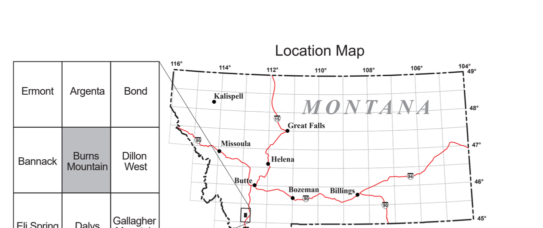
Cross Section A–A′



No vertical exaggeration.
Units not exposed in map area, but shown in cross section:
Kbel? Lower Beaverhead Group; see Mosolf (2021)
Tdwr? Dillon West Rhyolite; see McDonald and Mosolf (2023)

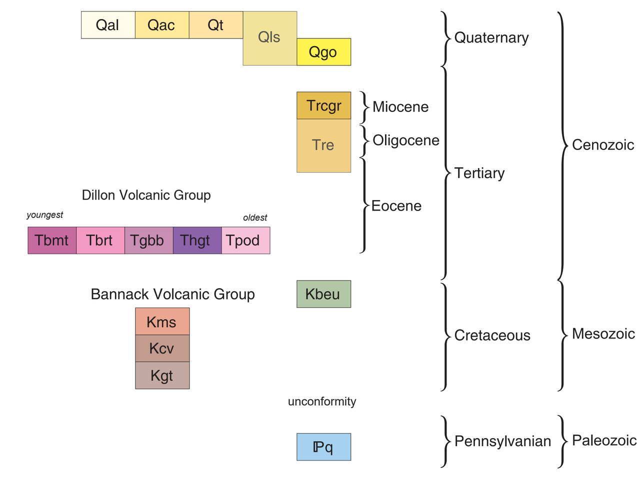
SCALE 1:24,000

Location Map

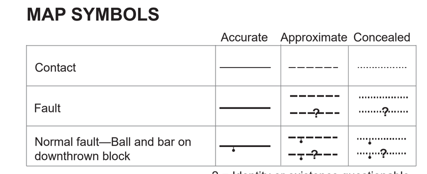


Research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award G19AC00229.
GIS production: Jesse Mosolf, Yiwen Li, and Patricia Ekberg, MBMG. Map layout: Susan Smith, MBMG. Editing: Susan Barth, MBMG.

CORRELATION DIAGRAM



MAP SYMBOLS



Contact
Fault
Normal fault—Ball and bar on downthrown block
? = Identity or existence questionable
Inclined fault, showing dip value and direction
Small, minor inclined joint, showing strike and dip
Inclined beds, showing strike and dip
Inclined cleavage, showing strike and dip
Horizontal flow banding in igneous rock
Igneous foliation, showing strike and dip
Inclined metamorphic foliation, showing strike and dip
Dry hole (wildcat well) API Well 25001600020000
Geochemistry sample location
Geochronology sample location with age

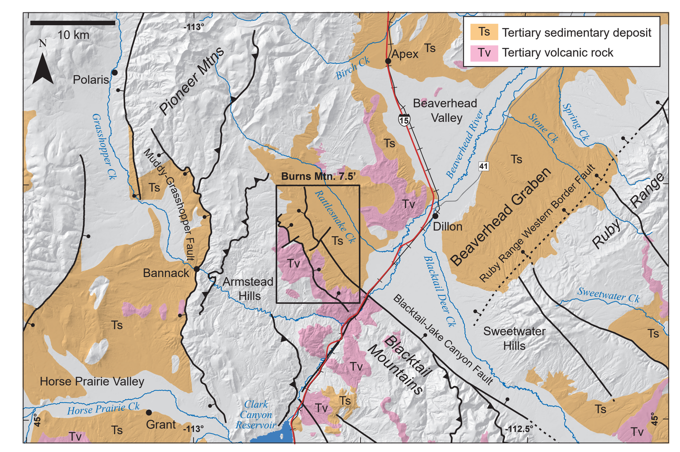


Figure 1. Physiographic map of the Dillon area showing the major structures and select geologic units overlain on a digitial elevation model (DEM) hillshade (10 m resolution). The geology is modified from Vuke and others (2007), Ruppel and others (1993), and mapping is this study.

LOCATION AND PHYSIOGRAPHIC SETTING

The Burns Mountain 7.5′ quadrangle is located in Beaverhead County, approximately 15 km (9.3 mi) west of Dillon, Montana. The quadrangle borders the southern Beaverhead Valley, spanning the Armstead Hills and the northwesterly extent of the Blacktail Mountains (fig. 1). The map area is characterized by hilly terrain covered by grasslands with excellent exposure of the bedrock geology locally. The volcanic units generally form low hills standing in relief against recessive Tertiary sedimentary deposits. Easterly dipping pediments are formed on sedimentary deposits flanking the Armstead Hills and are often covered with a veneer of gravel (< 2 m) not mappable at 1:24,000 scale. Expansive Quaternary glacial outwash deposits underlie the Argenta Flats adjacent to Rattlesnake Creek, a perennial stream and significant tributary to the Beaverhead River. The quadrangle elevation ranges from 1,615 to 2,105 m (5,300 to 6,900 ft).

GEOLOGIC SUMMARY

The Paleozoic Quadrant Formation (IPq) is the oldest bedrock unit exposed in the Burns Mountain quadrangle, occurring as two small outcrops (<0.1 km^2), one buttressing Timber Butte and the other underlying the low hills bordering the northeast side of Argenta Flats. The map area covers the eastern extent of Late Cretaceous sedimentary and volcanogenic deposits of the Upper Beaverhead Group (Kbeu) and Bannack Volcanic Group (Kgt, Kcv, and Kms). The Cretaceous units were synorogenic with Cordilleran crustal shortening, recording foreland sedimentation and volcanism as the thrust belt advanced eastward (Kalakay, 2001; Kalakay and others, 2001). The Eocene Dillon Volcanic Group unconformably overlies the Cretaceous and older units, comprising dacite porphyry (Tpod), mafic lava flows (Tgbb), and intercalated rhyolitic lava and tuff deposits (Tbmt, Tbrt, and Thgt). The Eocene magmatic units erupted in the footwall block of the Muddy–Grasshopper fault after local Cordilleran shortening ceased and crustal extension began (fig. 1; e.g., Jänecke and others, 1999; 2005; VanDenburg and others, 1998). Clastic sedimentary deposits of the Renova Formation (Tre) unconformably overlie the Cretaceous–Eocene volcanogenic units exhumed in the footwall of the Muddy–Grasshopper fault, resting on the older Cretaceous–Eocene volcanogenic units forming an angular uncomformity locally. Poorly lithified gravel deposits (Rattlesnake Creek gravel; Trcgr) unconformably rest on and are faulted against the Renova Formation and older map units, and likely correlate with the Miocene Sixmile Creek Formation in the upper Ruby Valley (Thomas and Sears, 2020). Expansive outwash deposits (Qgo) derived from the glaciation of the southern Pioneer Mountains underlie Argenta Flats in the north part of the quadrangle. Landslide deposits (Qls) mapped in the south part of the quadrangle are developed primarily in Eocene volcanic deposits. Two major northwest-striking extensional faults that transect much of the quadrangle deformed the Late Cretaceous through Miocene map units.

PREVIOUS MAPPING

The Burns Mountain 7.5′ quadrangle is included in small-scale mapping by Ruppel and others (1993, scale 1:250,000) and larger-scale mapping by Lowell (1965, scale 1:31,680). Mapping of the Tertiary sedimentary units was based on lithological descriptions by Ripley (1995), Thomas and others (1995), Fritz and others (2007), Sears and others (2009), Thomas and Sears (2020), and Vuke (2020). The Eocene volcanic map units were defined by lithology, age, geochemical composition, and mapping in this study, and previous unit descriptions by Fritz and others (2007). Informal subdivisions of the Beaverhead Group follow Lowell (1965) and Johnson (1986). Mapping of the Cretaceous igneous units was based on descriptions by Ivy (1988) and Pearson and Childs (1989).

METHODS

Geologic Mapping

Field mapping in the quadrangle was conducted over approximately 3.5 months in 2019 for the STATEMAP component of the United States Geological Survey (USGS) National Cooperative Geologic Mapping Program. A 1:24,000-scale topographic base was used for field mapping, and geologic contacts were refined using the 2017 orthoimagery dataset produced by the National Agricultural Imagery Program (NAIP). Structure and observational data were located with a handheld GPS device; structure data were measured with a traditional hand transit or mobile electronic device. Field sheets were georegistered in GIS software, and the geologic data were subsequently digitized to the Geologic Map Schema (GeMS) geodatabase from the the USGS.

Whole-Rock Geochemistry and U-Pb Geochronology

Rock samples collected for whole-rock geochemistry and U-Pb geochronology were processed at the MBMG Mineral Separation Laboratory. Approximately 100–200 g of the crushed material was prepared for bulk-rock geochemical analyses and subsequently analyzed by X-ray fluorescence and inductively coupled plasma mass spectrometry at the Peter Hooper GeoAnalytical Lab, Washington State University. Zircon was isolated from specimens using standard density and magnetic separation techniques at the MBMG Mineral Separation Laboratory. Zircon separates were analyzed by Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) at the University of California, Santa Barbara.

Whole-rock geochemical data and analytical methods are reported in Mosolf and McDonald (2024). Major and trace element data are plotted in figure 2. U-Pb zircon ages obtained for volcanic and sedimentary samples are reported in table 1; the age distributions for the sedimentary samples are plotted in figure 3. The complete U-Pb zircon datasets and analytical methods are provided in Mosolf and Kylander-Clark (in review).

DESCRIPTION OF MAP UNITS

The geologic map shows map units exposed at the surface or underlain by a thin surficial cover of soil and colluvium. Surficial sedimentary and mass movement deposits are shown where they are thick and extensive enough to be mapped at 1:24,000 scale. Igneous rocks are classified using the International Union of Geological Sciences nomenclature (Le Bas and Streckeisen, 1991). Minerals in igneous rock units are listed in order of decreasing abundance. Grain size classification of unconsolidated and consolidated sediment is based on the Wentworth scale (Lane, 1947). Multiple lithologies within a rock unit are listed in order of decreasing abundance.

Quaternary Geology

Extensive alluvial and colluvial sediments (Qaf and Qal) were deposited along Rattlesnake Creek and ephemeral stream tributaries. Alluvial deposits were challenging to map in agricultural areas with extensive stream modification. Landslide deposits (Qls) as big as 0.6 km^2 (0.23 mi^2) are developed primarily in Eocene volcanic deposits.

The Pioneer Mountains were glaciated throughout the Pleistocene, including the Pinedale and Bull Lake glaciations (Smith, 2007). Most of the glaciers in the Pioneer Mountains were valley glaciers, many of which formed extensive outwash fans along stream valleys downslope from glaciated areas. The large Pleistocene glacial outwash fan underlying the Argenta Flats was sourced from the Kelly Reservoir area in the southern Pioneer Mountains (Thomas and others, 2007).

Qal **Alluvium (Quaternary: Holocene)**—Poorly sorted gravel, sand, silt, and clay deposited by Rattlesnake Creek. Clasts are generally polymictic, subrounded to rounded pebbles and cobbles. Thickness is usually less than 6 m (20 ft).

Qac **Alluvium and colluvium (Quaternary: Holocene)**—Gravel, sand, and silt deposited by sheetwash alluvium and incorporated with locally derived colluvium. Formed in ephemeral stream drainages bordering Argenta Flats. Thickness generally less than 6 m (20 ft).

Qt **Talus (Holocene and Pleistocene)**—Unconsolidated angular debris that typically forms aprons on or below steep slopes. Includes some rock-slide deposits. Variable thickness, generally less than 10 m (33 ft).

Qls **Landslide deposit (Quaternary: Holocene)**—Unstratified, poorly sorted rock fragments deposited by slumps, slides, and debris flows. Typically characterized by hummocky topography and subdued landslide scarps. Variable thickness, typically less than 30 m (100 ft).

Qgo **Glacial outwash (Pleistocene)**—Poorly consolidated sand and polymictic gravel composed of rounded to subrounded cobbles and boulders of quartzite, granite, argillite, limestone, sandstone, and volcanic rock. A well log (API Well 25001600020000) from a wildcat well drilled in the northern part of the map area shows glacial outwash deposits as thick as 46 m (150 ft).

Tertiary Sedimentary Deposits

The Eocene–Miocene Renova Formation is the oldest Tertiary sedimentary unit in the map area, consisting of coarse clastic sediments shed from the exhumed footwall of the Muddy–Grasshopper fault and Eocene volcanic highlands to the west (fig. 1), possibly accumulating as growth strata. The younger Rattlesnake Creek gravel unconformably rests on the Renova Formation and older map units, and is likely correlative to the Miocene Sixmile Creek Formation in the Ruby Valley (Thomas and Sears, 2020). The gravel deposits accumulated in the western part of the Beaverhead Graben during middle Miocene extension (fig. 1; Sears and others, 2009). Thin gravel deposits (<1 m thick) covering pediments are likely sourced from the Rattlesnake Creek gravel.

Trcgr **Rattlesnake Creek gravel (middle to late Miocene?)**—Unlithified, poorly organized deposits of cobble to boulder (up to 2 m/6.6 ft) gravel in a matrix of silt and sand with rare sedimentary structures. Cobbles and boulders are poorly sorted, subangular to rounded, consisting of quartzite, sandstone, limestone, Eocene rhyolite and basalt, Cretaceous granitoids, and Archean gneiss. Clast abundance varies widely by location, with some deposits consisting of nearly 100 percent Eocene volcanic clasts. Gravel clasts in the northern part of the map area are stained yellow-brown to orange. As thick as 120 m (400 ft).

Tre **Renova Formation, undivided (late Eocene to early Miocene)**—Interbedded conglomerate, sandstone, siltstone, volcanic ash, and rare carbonate beds that progressively fine up-section (fig. 4A). Conglomerate beds are commonly channelized, approximately 15–80 cm (5.9–31.5 in) thick, and composed of poorly sorted, clast-supported, subrounded to rounded polymictic pebbles and cobbles with occasional boulders (up to 1 m/3.3 ft). Conglomerate clasts include Eocene volcanic rock (mostly basalt), quartzite derived from the Mesoproterozoic Belt Supergroup, Paleozoic quartzite and limestone, Cretaceous granitoids, and Archean gneiss, which together give outcrops a variegated appearance. Clast-type abundance varies widely by location, but Mesoproterozoic–Paleozoic quartzite and Eocene volcanic clasts typically occur equally. Multistory stacks of conglomerate alternate between pebble- and cobble-clast-dominated beds. Interbeds of gray, white, pale orange, and light brown siltstone, immature sandstone, and volcanic ash are poorly to well sorted and contain matrix-supported granules, pebbles, and cobbles locally. Fine-grained beds are lenticular, massive to finely bedded, and approximately 20–150 cm (7.9–59 in) thick. Rare intervals (<2 m/6.6 ft thick) of massive, calcified silt and sand occur locally. Distinguished from the Rattlesnake Creek gravel by a higher degree of induration and predominance of fine-grained intervals that often contain ash. Sandstone interbeds yielded U-Pb zircon maximum depositional ages of 25.4 ± 0.5 Ma and 21.0 ± 0.7 Ma (fig. 3). As thick as 90 m (300 ft).

Dillon Volcanic Group

The Eocene Dillon Volcanic Group comprises scattered outcroppings of dacite porphyry (Tpod; ~50 Ma) overlain by a bimodal sequence of mafic lava flows (Tgbb) intercalated with vent-proximal rhyolitic lava and tuff (Tbmt, Tbrt, and Thgt) erupted circa 48.4–46.6 Ma. The volcanogenic units are enriched in incompatible elements (fig. 2), reflecting fractionation, mixing, and assimilation of the parental melts inboard of an active plate margin. Emplacement of the Dillon Volcanic Group and subsequent fluvial sedimentation (Tre) were coeval with early slip and footwall exhumation of the Muddy–Grasshopper fault (fig.1; Jänecke and others, 2005).

Tbmt **Burns Mountain tuff (Tertiary: Eocene)**—Multistoried sequence of quartz–sanidine rhyolite ash flows (fig. 4B). The lower part of the sequence is composed of alternating white, brown, and gray-purple ash beds (1–10 m/3.3–32.8 ft thick) containing abundant pumice lapilli and bombs up to 20 cm/7.9 in mixed with poorly sorted accidental clasts of quartzite and volcanic rock fragments. Ash beds are weakly consolidated, show evidence of local fluvial reworking, and are intercalated with lenticular beds of polymictic cobble conglomerates near the base of the sequence. The upper part of the sequence grades into a gray, strongly welded rhyolite tuff containing broken phenocrysts of chatoyant sanidine (5–10 percent, 1–2 mm), smoky quartz (5–10 percent, 1–2 mm), and biotite (<1 percent, <1 mm) in a groundmass of welded glass shards. Rheomorphic deformation is common. The welded tuff is resistant to weathering, commonly forming conspicuous ridgelines. U-Pb zircon ages in the map area span 47.0 ± 0.5 Ma to 46.6 ± 0.3 Ma. As thick as 180 m (600 ft).

Tbrt **Barretts rhyolite and tuff (Tertiary: Eocene)**—Light pink, purple, and gray rhyolite occurring as resistant ridges and blocky outcrops. Contains phenocrysts of smoky quartz (<5 percent; 1–3 mm), euhedral plagioclase (<20 percent; 1–2 mm), euhedral biotite (<5 percent; <1 mm), and hornblende (<5 percent; 1 mm) in a waxy groundmass of cryptocrystalline quartz. Flow-banding, autobrecciation, and vitrophyre are common. In the adjacent 7.5′ quadrangles, a prominent interval of vitrophyre up to 10 m (33 ft) thick occurs near the base of the unit and rhyolite flows are intercalated with subordinate tuff intervals with a similar mineral assemblage. Rhyolite sample JM19BM01 yielded a U-Pb zircon age of 47.6 ± 0.3 Ma. As thick as 150 m (500 ft).

Tgbb **Gallagher Butte basalt (Tertiary: Eocene)**—Dark gray to black trachybasalt, basaltic trachyandesite, and andesite lava flows that commonly form prominent cliffs and mesas, and exhibit columnar joints locally. Lava flows are weakly porphyritic, containing <10 percent phenocrysts of olivine (1–3 mm), clino- and ortho-pyroxene (1–2 mm) with occasional plagioclase (1–2 mm), and deeply embayed, xenocrystic quartz (1–2 mm). The aphanitic groundmass typically has a trachytic texture consisting of aligned microcrystals of plagioclase but can also include olivine and pyroxene. Andesitic flows containing embayed quartz occur locally. As thick as 120 m (400 ft).

Thgt **Hennebury Gulch tuff (Tertiary: Eocene)**—White, light brown, and orange lithic–vitric tuff. Composed of crude, massive bedforms approximately 1–2 m (3.3–3.6 ft) thick. Contains broken phenocrysts (up to 30 percent) of quartz, feldspar, biotite, and occasional amphibole in a vitric groundmass composed of cuspate glass shards that are primarily fresh but are devitrified locally. Tuff intervals commonly include small fragments up to 5 mm/0.2 in of pumice, accidental volcanic clasts up to 1 m (3.3 ft), and petrified wood. Thin intervals of planar, low-angle, cross-bedded tuffaceous sandstone occur locally. This unit is generally not well exposed, forming slopes under resistant ridges of basaltic lavas (Tgbb). Sample JM19BM24 yielded a U-Pb zircon age of 48.4 ± 0.4 Ma. As thick as 150 m (500 ft).

Tpod **Pipe Organ dacite (Tertiary: Eocene)**—Scattered outcrops of hornblende dacite porphyry containing crowded phenocrysts of plagioclase (10–20 percent; up to 4 mm); stubby to tabular hornblende (15–20 percent; up to 7 mm); and quartz (<5 percent; up to 3 mm) in a gray to pink groundmass of weakly aligned plagioclase and subordinate Fe-oxide microlites. Quartz and plagioclase phenocrysts are commonly embayed or skeletal. Weakly porphyritic and flow-banded locally. Porphyritic rock is dense and weathers into resistant blocks. Flow-banded rocks form flaggy outcrops and talus. Dacite porphyry is locally intercalated with tephra deposits with similar mineral assemblages. U-Pb zircon ages span 50.0 ± 0.3 Ma to 49.2 ± 0.4 Ma. Thickness in the map area unknown.

Table 1. U-Pb zircon geochronology

Sample	Lithology	Unit	Latitude (°N)	Longitude (°W)	Total # of spot analyses[a]	# spots Age Calc[b]	Age (Ma)	2σ	MSWD
JM19BM17	sandstone	Tre	45.1534	-112.7843	180	6	21.0	0.7	2.40
JM19BM16	sandstone	Tre	45.1503	-112.7994	184	11	25.4	0.5	3.10
JM19BM08	rhyolite	Tbmt	45.1385	-112.7921	40	34	46.6	0.3	0.57
JM19BM27	rhyolite tuff	Tbmt	45.1723	-112.8129	38	19	47.0	0.5	0.53
JM19BM01	rhyolite	Tbrt	45.1263	-112.7519	40	31	47.6	0.3	0.90
JM19BM24	rhyolite tuff	Thgt	45.1697	-112.8284	40	29	48.4	0.4	0.79
JM19BM23	dacite	Tpod	45.1695	-112.8155	37	26	49.2	0.4	0.85
JM19BM35	tuff	Tpod	45.1567	-112.8642	36	14	49.4	0.4	0.84
JM19BM40	dacite	Tpod	45.1760	-112.8544	40	29	50.0	0.3	0.98
JM19BM41	tuff	Kgt	45.2197	-112.8685	38	9	75.3	0.9	0.11

Note. Reported ages are the weighted mean of the ^{207}Pb corrected ^{206}Pb/^{238}U ages obtained for each sample.
MSWD is the Mean Square Weighted Deviation.
[a]Total number of spot analyses.
[b]Number of spot analyses used to calculate weighted mean age.
Zircon separates were prepared at MBMG and analyzed by LA-ICPMS at the University of California, Santa Barbara.
Latitudes and longitudes are in the 1984 World Geodetic Survey (WGS84) datum.

Upper Cretaceous Igneous and Sedimentary Deposits

The map area covers the eastern extent of the Upper Cretaceous Bannack Volcanic Group, consisting of a complex sequence of lavas, volcanic breccias, tuff deposits, and subvolcanic intrusions (Kms, Kcv, and Kgt) with dominantly andesite–dacite compositions and enrichment in incompatible elements indicative of continental arc-type magmatism (fig. 2; Ivy, 1988). The volcanic units are intercalated with synorogenic sedimentary rocks of the Beaverhead Group (Kbeu). In the adjacent Bannack and Dalys 7.5′ quadrangles, U-Pb dating of detrital zircon from the Lower Beaverhead (not exposed in the map area) and Upper Beaverhead Group yielded max depositional ages of 77.9 Ma and 67.5 Ma, respectively (Laskowski and others, 2013; Garber and others, 2018). Contractional faults and folds deform the upper Cretaceous volcanic and sedimentary units throughout the Armstead Hills (fig. 1), constraining synorogenic sedimentation, magmatism, and crustal shortening to approximately 78–67 Ma (Kalakay, 2001; Kalakay and others, 2001).

Kbeu **Upper Beaverhead Group (Upper Cretaceous)**—Poorly lithified conglomerate beds composed of clast-supported, well-rounded, and imbricated pebbles and cobbles. Approximately 50–80 percent of the clasts are red- to maroon-weathering quartzite derived from the Mesoproterozoic Belt Supergroup, and the remainder are Paleozoic limestone, quartzite, chert, and rare dacite–andesite clasts that are deeply weathered. Conglomerate beds are 10–100 cm (4–39 in) thick and have tabular and lenticular geometries. The lower part of the unit contains thin interbeds (<2 m) of freshwater limestone. Thickness as much as 400 m (1,300 ft).

Kms **McDowell Springs granodiorite, Bannack Volcanic Group (Upper Cretaceous)**—Gray-green- to brown-weathering diorite and granodiorite porphyry containing phenocrysts of plagioclase, pyroxene, biotite, hornblende, and rare quartz in a groundmass of plagioclase and altered mafic microlites with abundant magnetite. Commonly exhibits flow banding and columnar jointing. Occurs as large sheet-like bodies up to 300 m (985 ft) thick that weather to prominent buttes and hoodoos throughout the Armstead Hills.

Kcv **Cold Spring Creek formation, Bannack Volcanic Group (Upper Cretaceous)**—Complex, intertonguing sequence of porphyritic lava flows, volcanic breccia, and ash-flow tuff that are poorly exposed in the map area. The following description is mainly based on observations in the neighboring 7.5′ quadrangles. Porphyritic lavas are typically dark colored and contain crowded phenocrysts of plagioclase, orthopyroxene, clinopyroxene, hornblende, biotite, and quartz in a plagioclase–phyric groundmass with abundant Fe-Ti oxides. Intercalated volcanic breccias commonly occur as massive, greenish gray intervals 3–5 m (10–16 ft) thick, composed of poorly sorted, subrounded-to-subangular clasts of andesite–dacite porphyry. Discontinuous tuff interbeds are 2–10 m (6–16 ft) thick and contain broken phenocrysts of plagioclase, hornblende, rare quartz, and accidental volcanic clasts in a eutaxitic groundmass of devitrified and flattened glass shards. Tuff intervals contain varying amounts of pumice fragments and accidental clasts of porphyry lava. Mosolf (2021) reported three U-Pb zircon ages of approximately 72 Ma for this unit in the Eli Spring 7.5′ quadrangle to the southwest. Ivy (1988) reported unreconcilable ^{40}Ar/^{39}Ar hornblende ages spanning 80–76 Ma. Thickness in the Armstead Hills is as much as 490 m (1,600 ft).

Kgt **Grasshopper Creek tuff, Bannack Volcanic Group (Upper Cretaceous)**—White, light gray, yellowish gray, and pale red deposits of thin-bedded vitric tuff and massively bedded crystal–lithic rhyolitic tuff that are poorly exposed in the map area. Tuff deposits contain varying proportions of sanidine, quartz, and plagioclase crystals, and accidental fragments of volcanic and sedimentary rock in a matrix of glass shards that are mostly zeolitized and silicified. Commonly exhibits compaction foliation formed by the collapse of pumice fragments; strongly welded intervals occur locally. Sample JM19BM41 yielded a U-Pb zircon age of 75.3 ± 0.9 Ma. Mosolf (2021) reported a U-Pb zircon age of 74.7 ± 1.2 Ma for this unit in the Eli Spring 7.5′ quadrangle, and Kalakay (2001) reported a SHRIMP U-Pb zircon age of 75.1 ± 1.1 Ma in the Bannack area. Thickness in the Armstead Hills is as much as 300 m (1,000 ft).

Paleozoic Sedimentary Rocks

The Quadrant Formation is the oldest unit and the only Paleozoic formation exposed in the map area. Quartzite at Timber Butte appears to rest on Eocene dacite porphyry (Tpod) and is suspected to be a large landslide block intercalated with the Rattlesnake Creek gravel unit. Alternately, the Quadrant Formation is intruded by the porphyry at this location.

IPq **Quadrant Formation (Pennsylvanian)**—Light gray to light yellowish brown, fine-grained, vitreous quartz sandstone. Beds are thick to massive and occasionally exhibit faint cross-laminations. Forms a resistant knob at Timber Butte that is covered with conifers. As thick as 300 m (985 ft) in the Armstead Hills.

STRUCTURAL GEOLOGY

The northwest-striking Tenmile House and Timber Butte faults span much of the quadrangle, gently tilting the Tertiary volcano-sedimentary units (fig. 5) and forming an extensional graben up to approximately 3 km (1.9 mi) wide in the northern part of the map area. Both faults progressively steepen to near-vertical geometries along their southern traces and are structurally linked to secondary normal faults and northeast-striking transfer faults. The northern segment of the Tenmile House fault dips approximately 20–30° to the west–southwest, juxtaposing the Renova Formation and Rattlesnake Creek gravel with an estimated vertical displacement of 135 m (443 ft). Southward, the fault steepens and flips polarity across a transfer fault, dipping 80° northeast in an unnamed drainage along its southerly trace (section 1, T. 8 S., R. 10 W.). The northern segment of the Timber Butte fault dips 30–40° to the east–northeast and progressively steepens to over 70° along its southern trace. The fault deformed Tertiary sedimentary and volcanogenic strata, locally placing deposits of the Rattlesnake Creek gravel against the Dillon Volcanic Group with an estimated vertical separation of 625 m (2,050 ft). The Tenmile House and Timber Butte faults are *en échelon* with the Quaternary-active Blacktail–Jake Canyon fault, possibly representing a previously unrecognized segment of the fault system (fig. 1; Tysdal, 1988; Crawford and Pearson, 2017).

ACKNOWLEDGMENTS

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REFERENCES

Crawford, B.M. and Pearson, D.M., 2018, Geologic map of the Ashbough Canyon 7.5′ quadrangle, Beaverhead County, Montana: Montana Bureau of Mines and Geology EDMAP 12, 1 sheet, scale 1:24,000.
Fritz, W.J., Sears, J.W., McDowell, R.J., and Wampler, J.M., 2007, Cenozoic volcanic rocks of southwestern Montana: Northwest Geology, v. 36, p. 91–110.
Garber, K.L., Finzel, E.S., and Rosenblume, J.A., 2018, Sedimentology and detrital geochronology of the Late Cretaceous Beaverhead Group, southwest Montana: Geological Society of America Abstracts with Programs, v. 50, no. 6, abstract 268–3, https://doi.org/10.1130/abs/2018AM-322419.
Ivy, S.D., 1988, Source, evolution, and eruptive history of the Cold Spring Creek volcanics, Beaverhead County, Montana: Corvallis, Oregon State University, M.S. thesis, 132 p.
Jänecke, S.U., McIntosh, W., and Good, S., 1999, Testing models of rift basins—Structure and stratigraphy of an Eocene–Oligocene supradetachment basin, Muddy Creek half graben, southwest Montana: Basin Research, v. 11, no. 2, p. 143–167.
Jänecke, S.U., Dorsey, R.J., Kickham, J., Matoush, J.P., and McIntosh, W., 2005, Geologic map of the Bachelor Mountain 7.5′ quadrangle, southwest Montana: Montana Bureau of Mines and Geology Open-File Report 525, 28 p., 1 sheet, scale 1:24,000.
Johnson, L.M., 1986, An overlap zone between a Laramide Rocky Mountain foreland structure and Sevier-style thrust structures near Bannack, Montana: University of Montana, Missoula, M.S. thesis, 47 p., 2 sheets, scale: 1:24,000.
Kalakay, T.J., 2001, The role of magmatism during crustal shortening in the retroarc fold and thrust belt of southwest Montana: Laramie, University of Wyoming, Ph.D. dissertation, 204 p.
Kalakay, T.J., John, B.E., and Lageson, D.R., 2001, Fault-controlled pluton emplacement in the Sevier fold-and-thrust belt of southwest Montana, USA: Journal of Structural Geology, v. 23, no. 6–7, p. 1151–1165.
Lane, E.W., 1947, Report of the subcommittee on sediment terminology: Transactions of the American Geophysical Union, v. 28, no. 6, p. 936–938.
Laskowski, A.K., DeCelles, P.G., and Gehrels, G.E., 2013, Detrital zircon geochronology of Cordilleran retroarc foreland basin strata, western North America: Tectonics, v. 32, p. 1027–1048.
Le Bas, M.J., LeMaitre, R.W., Streckeisen, A., and Zanettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali silica diagram: Journal of Petrology, v. 27, p. 745–750.
Le Bas, M.J., and Streckeisen, A.L., 1991, The IUGS systematics of igneous rocks: Journal of the Geological Society of London, v. 148, p. 825–833, https://doi.org/10.1144/gsjgs.148.5.0825.
Lowell, W.R., 1965, Geologic map of the Bannack-Grayling area, Beaverhead County, Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-433, scale 1:31,680.
McDonald, C., and Mosolf, J.G., 2023, Geologic map of the Dillon West 7.5′ quadrangle, Beaverhead County, Montana: Montana Bureau of Mines and Geology Geologic Map 91, 1 sheet, scale 1:24,000.
Mosolf, J.G., 2021, Geologic map of the Eli Spring 7.5′ quadrangle, Beaverhead County, Montana: Montana Bureau of Mines and Geology Geologic Map 81, 1 sheet, scale 1:24,000.
Mosolf, J.G., and McDonald, C., 2024, Major oxide and trace element analyses of rock samples collected in the Dillon 30′ x 60′ quadrangle, southwest Montana, 2019-2020: Montana Bureau of Mines and Geology Analytical Dataset 9.
Mosolf, J.G., and Kylander-Clark, A., in review, LA-ICPMS U-Pb geochronology data from rock samples collected in the Butte North, Dillon, Hamilton, Polson, and Wisdom 30′ x 60′ quadrangles, western Montana, 2019–2020: Montana Bureau of Mines and Geology Analytical Dataset XX.
Pearson, R.C., and Childs, J.F., 1989, Field trip guide, roadlog, and summary of Cretaceous volcanic geology, Dillon to Bannack, Beaverhead County, Montana: Northwest Geology, v. 18, p. 36–59.
Ripley, A., 1995, Tertiary carbonates in the upper Ruby and Jefferson River valleys, Montana: Northwest Geology, v. 25, p. 47–77.
Ruppel, E.T., O′Neill, J.M., and Lopez, D.A., 1993, Geologic map of the Dillon 1° x 2° quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I-1803-H, scale 1:250,000.
Sears, J.W., Hendrix, M.S., Thomas, R.C., and Fritz, W.J., 2009, Stratigraphic record of the Yellowstone hotspot track, Neogene Sixmile Creek Formation grabens, southwest Montana: Journal of Volcanology and Geothermal Research, v. 188, p. 250–259.
Smith, L., 2007, Quaternary geology of the Dillon area, Beaverhead County, Montana: Northwest Geology, v. 36, p. 143–150.
Sun, S.S., and McDonough, W.F., 1989, Chemical and isotope systematics of oceanic basalts: Implications for mantle composition and processes, *in* Saunders, A.D., and Norry, M.J., eds., Magmatism in the ocean basins: Geological Society, London, Special Publications, v. 42, p. 313–345.
Thomas, R.C., Sears, W.S., Ripley, A.A., and Berg, R.B., 1995, Tertiary extensional history of southwestern Montana: Field trip guide for the Sweetwater and upper Ruby valleys, Montana: Northwest Geology, v. 25, p. 5–25.
Thomas, R.C., Smith, L.N., and Roberts, S., 2007, A field guide to the glacial geology of the Birch Creek and Rattlesnake Creek areas, Beaverhead County, Montana: Northwest Geology, v. 36, p. 261–268.
Thomas, R.C., and Sears, J.W., 2020, Middle Miocene through Pliocene sedimentation and tectonics in Montana: A record of the outbreak and passage of the yellowstone hotspot, *in* Metesh, J.J., and Vuke, S., eds.: Montana Bureau of Mines and Geology Special Publication 122: Geology of Montana—Geologic History, v. 1, 25 p., available at http://www.mbmg.mtech.edu/pubs/GeologyofMontana/
Tysdal, R.G., 1988, Geologic map along the northeast side of the Blacktail Mountains, Beaverhead County, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-2041, scale 1:24:000.
VanDenburg, C.J., Jänecke, S.U., and McIntosh, W.C., 1998, Three-dimensional strain produced by >50 My of episodic extension, Horse Prairie basin area, SW Montana, U.S.A.: Journal of Structural Geology, v. 20, p. 1747–1767.
Vuke, S.M., 2020 The Eocene through early Miocene sedimentary record in western Montana, *in* Metesh, J.J., and Vuke, S., eds.: Montana Bureau of Mines and Geology Special Publication 122: Geology of Montana—Geologic History, v. 1, 38 p., available at http://www.mbmg.mtech.edu/pubs/GeologyofMontana/
Vuke, S.M., Porter, K.W., Lonn, J.D., and Lopez, D.A., 2007, Geologic map of Montana: Montana Bureau of Mines and Geology Geologic Map 62, 73 p., 2 sheets, scale 1:500,000.

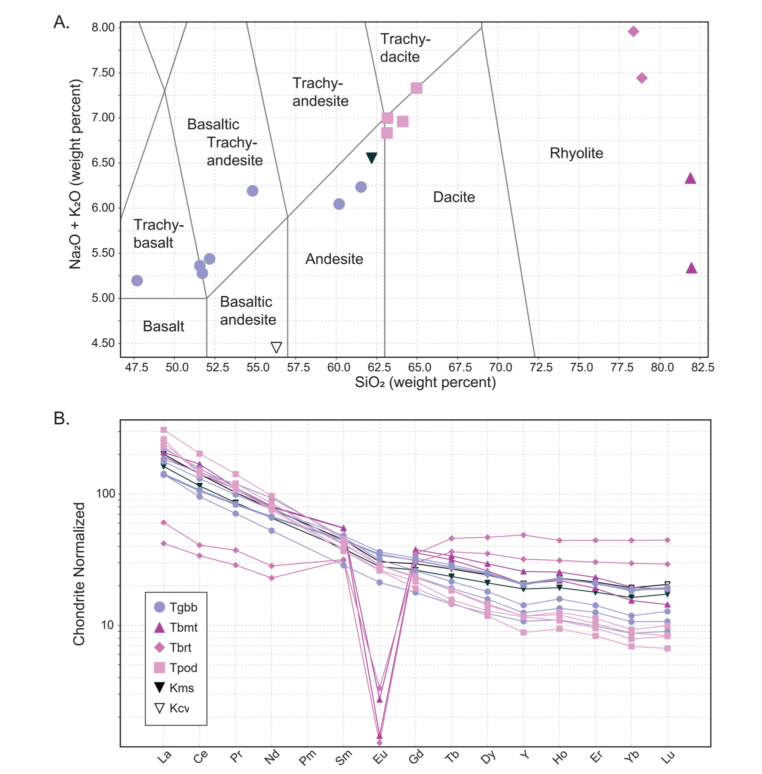

Figure 2. Major and trace element whole-rock geochemical data. (A) Total alkali silica classification diagram of normalized values after Le Bas and others (1986). (B) Chondrite-normalized rare earth element plot after Sun and McDonough (1989). Data are colored by formation; plots share the legend in B. See Mosolf and McDonald (2024) for a complete list of samples analyzed and full analytical datasets.

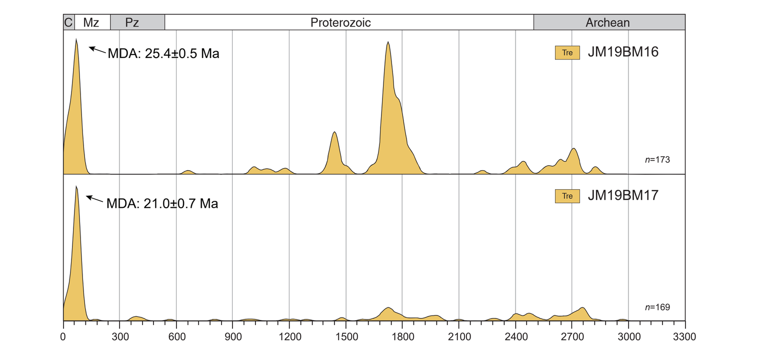

Figure 3. Kernel Density Estimate (KDE) plots of LA-ICPMS detrital zircon geochronology data from the Tertiary Renova Formation. KDE plots include the ^{207}Pb corrected ^{206}Pb/^{238}U (<1,400 Ma) and ^{207}Pb/^{206}Pb (>1,400 Ma) zircon age dates. KDE bandwidths are 200 m.y. and bin widths are 50 m.y. A 20% discordance filter was applied to the data. C, Cenozoic; Mz, Mesozoic; Pz, Paleozoic.

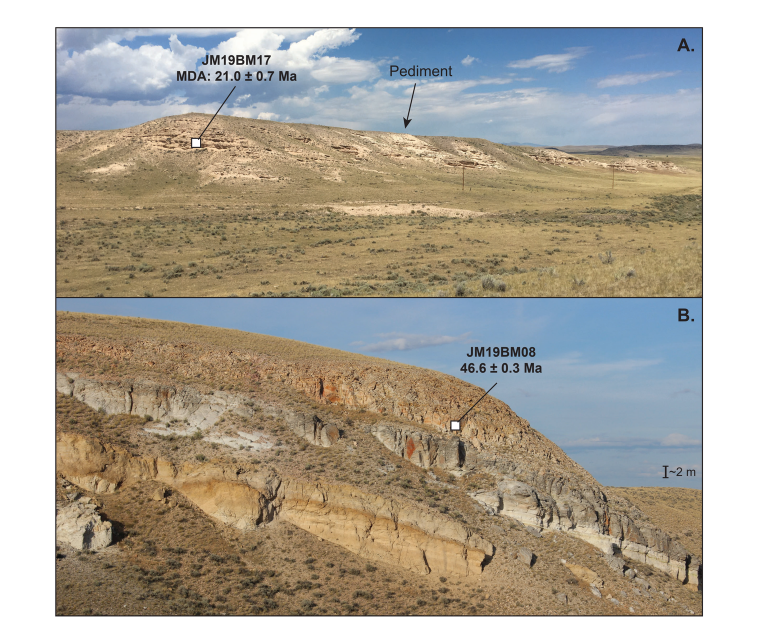

Figure 4. Tertiary volcanic and sedimentary deposits. (A) Eastward tilted panel of the Renova Formation, consisting of conglomerate, sandstone, siltstone, and volcanic ash. Note the pediment surface developed on the sedimentary deposits. Powerline for scale. (B) Gently tilted sequence of rhyolitic tuff and ignimbrite composing the Burns Mountain tuff. Sample JM19BM08 was taken from the welded tuff capping the sequence.

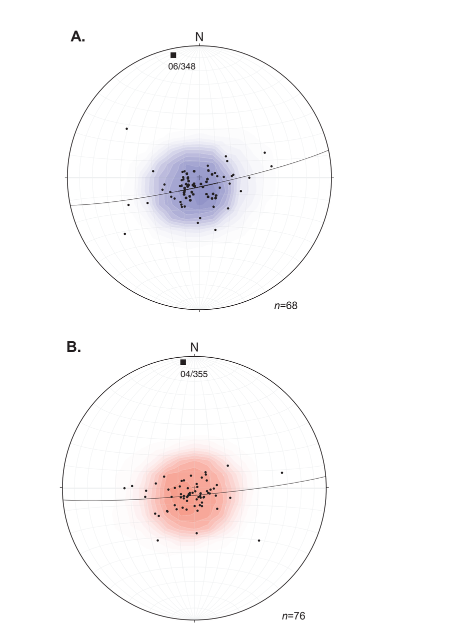

Figure 5. Lower-hemisphere projection of poles to bedding measurements in sedimentary (A) and volcanic (B) units. The data are plotted on an equal-area stereonet and fit with a Kamb contour. The great circle represents the cylindrical best fit with the corresponding fold hinges marked by a black square labeled with plunge and trend.

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Geologic Map 96

Geologic Map of the Burns Mountain 7.5′ Quadrangle, Beaverhead County, Montana

Jesse G. Mosolf

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