GEOLOGIC MAP OF THE NORTHERN PART OF THE LEADORE QUADRANGLE, LEMHI COUNTY, IDAHO

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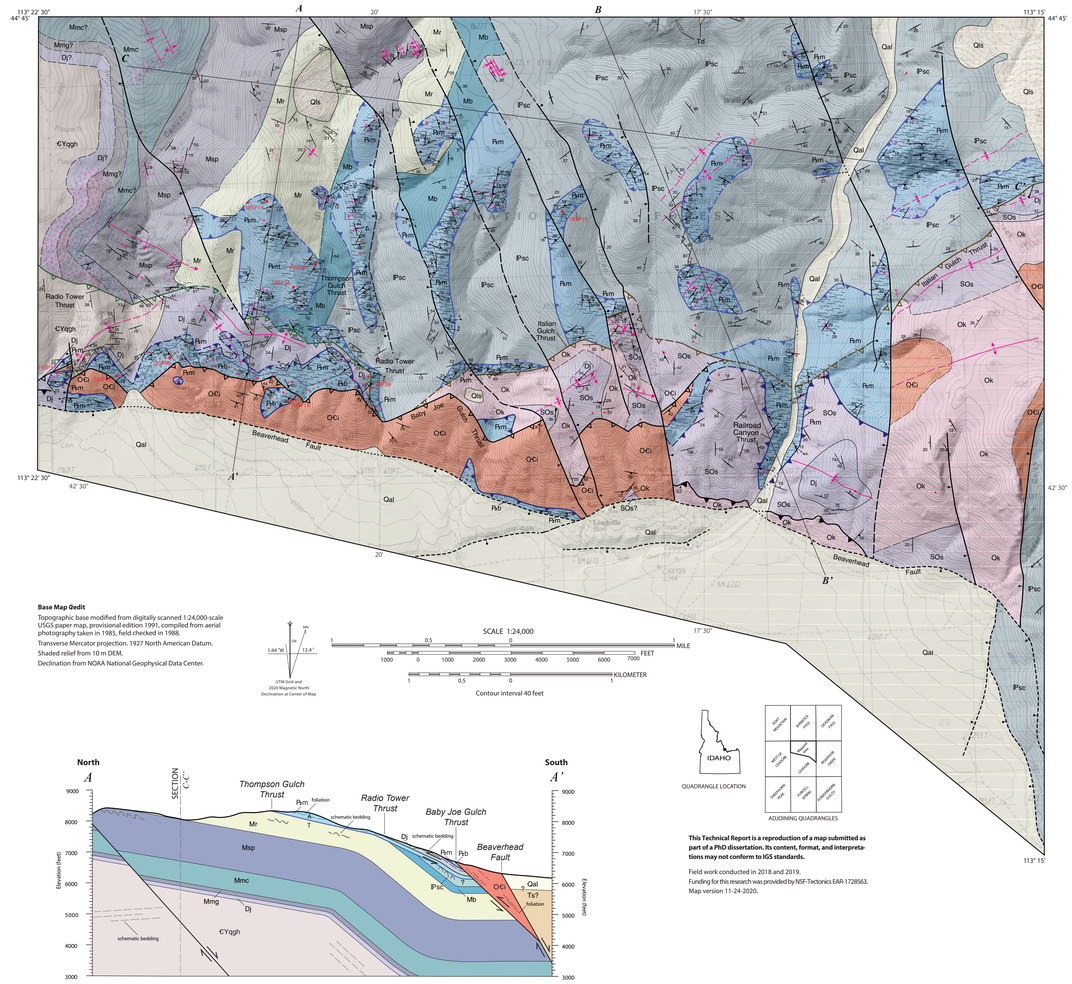

Base Map Qedit

Topographic base modified from digitally scanned 1:24,000-scale USGS paper map, provisional edition 1991, compiled from aerial photography taken in 1985, field checked in 1988.

Transverse Mercator projection. 1927 North American Datum.

Shaded relief from 10 m DEM.

Declination from NOAA National Geophysical Data Center.

This Technical Report is a reproduction of a map submitted as part of a PhD dissertation. Its content, format, and interpretations may not conform to IGS standards.

Field work conducted in 2018 and 2019.

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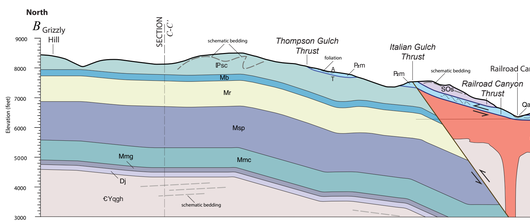
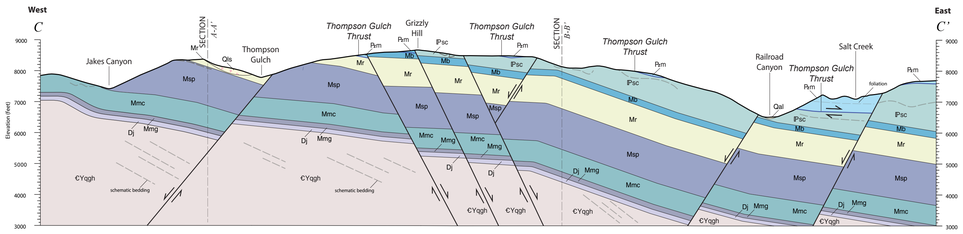
Map version 11-24-2020.





CORRELATION OF MAP UNITS

INTRODUCTION

This map is the result of fieldwork conducted in 2018 and 2019. Prior mapping results within the study area were published by Ruppel (1:62,500-scale; 1968), Ruppel and Lopez (1:200,000-scale; 1988), Ruppel (1:100,000-scale; 1998), Evans and Green (1:100,000-scale; 2003), and Lund (1:50,000-scale; 2018). These maps showed many low-angle thrusts primarily within Paleozoic rocks within the current map area, as well as a significant thrust fault near the southern Beaverhead Mountains range front. Recent mapping (1:24,000-scale) of the adjacent Bannock Pass quadrangle to the north by the Montana Bureau of Mines and Geology and Idaho Geological Survey (Lonn and others, 2019) documented a sub-Devonian angular unconformity and a generally intact, southeast-dipping section of sedimentary rocks ranging from Devonian to Pennsylvanian in age, which is underlain in angular unconformity by Mesoproterozoic to Cambrian(?) quartzite. This revised stratigraphic framework precludes the need for many of the previously mapped low-angle thrusts within the Bannock Pass and northern Leadore quadrangles. The opportunity to investigate the potential juxtaposition of bedding-parallel and high angle thrusts within the map area, coupled with the newly documented intact stratigraphy hypothesized to project southward into the current map area, were the main motivations to revisit the northern Leadore quadrangle during our 1:24,000-scale mapping campaign. Our work was supplemented by attitudes from Ruppel (1968) in the northeastern portion of the map area and we adopt the thrust nomenclature of Lund (2018) where appropriate.

We use the simplified stratigraphic framework of Lonn et al. (2019) as the basis for our mapping of sedimentary rocks in the northern part of the map area. This includes the lowermost Quartzite of Grizzly Hill, which is overlain in angular unconformity by the Devonian Jefferson Formation up to the Pennsylvanian Snaky Canyon Formation. In contrast to this "northern" stratigraphy, rocks near the range front north of Leadore in the hanging walls of the Italian Gulch and Railroad Canyon thrusts carry Ordovician/Cambrian Beaverhead pluton and nonconformably overlying Ordovician Kinnikinic Quartzite, Silurian to Ordovician Saturday Mountain Formation, and Devonian Jefferson Formation. This heterogeneity in stratigraphy across the map area is interpreted to be the result of two "overlapping" unconformities within the map area: (1) an Ordovician unconformity generally exposed within the Lemhi Range in east-central Idaho, which is overlain by Kinnikinic Quartzite; and (2) a Devonian unconformity generally exposed within southwestern Montana (Sloss, 1954; Grader and others, 2016).

In the northern part of the map area, our mapping results agree with the generally southeast-dipping stratigraphic section described in the Bannock Pass quadrangle to the north. Farther south in the map, these rocks are structurally overlain by strongly foliated carbonate mylonite with a prominent stretching lineation (Fig. 1); these tectonites are interpreted to represent a regional shear zone with a thrust sense of displacement. This mylonite armors many of the ridges near the range front. This thrust has some similar characteristics as the "Thompson Gulch thrust" described by Lund (2018), so we retain that name. Farther south, these rocks are, in turn, truncated by a south-southwest-dipping thrust fault that Lund (2018) named the "Baby Joe Gulch thrust". The exposed hanging wall of the Baby Joe Gulch thrust of Lund (2018) contains Cambrian/Ordovician plutonic rocks and Ordovician to Silurian sedimentary rocks not present in the Bannock Pass quadrangle. North-northwest-striking normal faults truncated all rock units and older faults within the map area; the main range front of the Beaverhead Mountains north of Leadore is bounded by the active Beaverhead normal fault and represents the southern boundary of bedrock mapping conducted during the present study.

SYMBOLS

Sense of slip (in cross section): A, away from observer; T, toward observer.

Lithostratigraphic contact: dashed where approximately located; dotted where concealed.

Tectonostratigraphic contact between mylonite and breccia: dashed where approximately located.

Thrust fault: teeth on hanging wall; dashed where approximately located; dotted where concealed; arrow indicates dip; question mark where poorly known; color coded with name labeled near type locality.

Thompson Gulch thrust

Railroad Canyon thrust

Baby Joe Gulch thrust

Italian Gulch thrust

Radio Tower thrust

Normal fault: ball and bar on hanging wall; long dashes where approximately located; short dashes where location inferred; dotted where concealed.

Anticline axial trace; dashed where approximately located; dotted where concealed; question mark where existence questionable; plunge direction shown.

Syncline axial trace; dashed where approximately located; dotted where concealed; question mark where existence questionable; plunge direction shown.

Overturned anticline axial trace; dashed where approximately located; dotted where concealed; plunge shown.

Overturned syncline axial trace; dashed where approximately located; dotted where concealed; plunge shown.

Monocline axial trace; dashed where approximately located; arrow on steep limb.

Strike and dip of bedding.

Strike and dip of bedding where sedimentary structures show bedding to be upright.

Strike of vertical bedding.

Strike and dip of overturned bedding.

Strike and dip of foliation; arrow shows trend and plunge of stretching lineation.

Strike and dip of pressure solution cleavage.

Trend of minor fold hinge.

19SP19 Sample locality of oriented thin section.

Tectonic breccia outcrop.

Mylonite outcrop.

Silicified outcrop.

DESCRIPTION OF MAP UNITS

Grain size classification of unconsolidated and consolidated sediment is based on the Wentworth scale (Lane, 1947). Carbonate rocks are described using Dunham's (1962) classification. Unit thicknesses and map distances are listed in metric units, with imperial units listed in parentheses. Multiple lithologies within a rock unit are listed in order of decreasing abundance. Intrusive rocks are classified according to IUGS nomenclature using normalized values of modal quartz (Q), alkali feldspar (A), and plagioclase (P) on a ternary diagram (Streckeisen, 1976). Volcanic rock compositions were not studied here in detail. Compositional names for small exposures of Cenozoic dikes are from Ruppel (1968).

ALLUVIAL DEPOSITS

Qal **Alluvium (Holocene)**—Sub-rounded to angular, unconsolidated cobble-gravel and sand. Modern stream, flood-plain, and alluvial fan deposits. Includes valley fill. Thickness varies considerably, but is usually from 1-3 m (3-10 ft) in mountain canyons. Fill of Beaverhead Valley is likely substantially thicker.

MASS-MOVEMENT DEPOSITS

Qls **Landslide deposits (Holocene to Pleistocene?)**—Poorly-sorted, unconsolidated sediments resulting from downhill movement. Mapped on the basis of hummocky topography and the presence of a head scarp. Typically associated with the shaley Railroad Canyon Formation.

CENOZOIC INTRUSIVE ROCKS

Td **Diabase (Eocene?)**—Medium dark gray to dark gray, very fine- to fine-grained, and porphyritic. Anhedral crystals 2-3 mm in diameter, of altered plagioclase feldspar. Subhedral to euhedral crystals 1-2 mm long of hornblende. Poorly exposed. Typically in dikes 1-3 m thick (3-10 ft), less commonly 15-30 m thick (50-100 ft).

STRONGLY TECTONIZED PALEOZOIC STRATA

Pzp Calcareous breccia undifferentiated (Paleozoic)— Gray to tan, massive brecciated limestone and dolostone. Yellow weathering, forming resistant fins and low cliffs near the Baby Joe Gulch thrust fault between Jakes Canyon and Italian Gulch. Occasionally crudely foliated subparallel to the thrust contact. Poorly sorted, sub-angular calcitic clasts range in size from coarse sand to pebble and are matrix supported. Approximate thickness of about 10-20 m (30-65 ft) where mapped as a discrete unit. Elsewhere, smaller occurrences of similar rocks are not of mappable size and are commonly associated with calcareous mylonite (Pzm).

Pzm Calcareous mylonite undifferentiated (Paleozoic)— Light- to dark-gray, calcareous mylonite with well-developed foliation and calcite stretching lineation (Fig. 1). Light-gray to tan, flaggy-weathering, forming slopes with chippy float, and defining prominent linear ridges in the central part of the map area. Composition ranges from entirely calcareous, to partly siliceous, with siliceous material defining mm-scale laminations, cm-scale layering, and 3-10 cm-scale isoclinal and sheath folds (Fig. 2). Isoclinal and sheath fold axial surfaces are subparallel to the foliation; fold axes, where measurable, are generally parallel to the stretching lineation and are interpreted to have formed concurrently with mylonitization (Fig. 3). Stretched crinoid ossicles observed on some foliation planes display long axes parallel to the stretching lineation. Mylonite exposures are bounded by distinct brittle fault contacts in several locations, including Thompson Gulch, Railroad Canyon, and Jakes Canyon. In other locations, such as ridges bounding Baby Joe Gulch, mylonite is interspersed with limestone, dolostone, and breccia. Between Jake Canyon and Thompson Gulch, calcareous breccia (Pzb) structurally overlies ~ 1 m thick, black, lavender-weathering, silicified shale, which, in turn, overlies calcareous mylonite. Mylonite is interpreted to represent a major, low-angle thrust fault zone with a predominantly eastward transport direction (Fig. 4). Protolith was assigned to the Middle Canyon Formation by Lund (2018). Apparent thickness ranges from 40-80 m (130-260 ft) based on good exposures in Thompson Gulch and Railroad Canyon.

PALEOZOIC STRATA

IPsc **Snaky Canyon Formation (Pennsylvanian)**—Gray to brownish-gray, limy and dolomitic wackestone and packstone, chert-rich silty lime mudstone, and yellowish-brown quartz arenite with calcitic cement. Lower part is sandy, with abundant fossiliferous thick- to thin-bedded wackestones-packstones. Bivalves, brachiopods, crinoids, corals, and bryozoans are common. Chert (including wood-grain chert of DeCelles, 1983) is common, ranging from isolated nodules to irregular beds of nodular chert. Tabular beds of alternating wackestone to silty lime mudstone with chert are common on 10-50 cm scale, occasionally in sharp contact with tabular beds of 1-2 m of fine quartz arenite. Upper section consists of dolomitic wackestone with sparse chert or sand. Rare, rounded, spherical algal laminations of several centimeters in diameter were found in dolomitic wackestone of the upper section. Fresh surfaces are muddy gray to dull in color. Weathered surfaces are earthy brown. The presence of sandstone distinguishes this unit from Mississippian limestones. Lower section may be partly correlative with Bloom member of Skipp and others (1979) and the Quadrant Formation of Lucchitta (1966). Upper section may be partly correlative with the Juniper Gulch member of Skipp and others (1979) and the Park City Formation of Cressman and Swanson (1964) and Lucchitta (1966). Gradational lower contact with Bluebird Mountain Formation. Top contact not observed in mapped area. Local thickness is likely ~800 m (~2600 ft), based on measured sections in Hawley Creek, < 10 km (6 mi) to the southeast (Cressman and Swanson, 1964), and near Morrison Lake, MT, ~ 20 km (12 mi) to the southeast (Lucchitta, 1966).

Mb **Bluebird Mountain Formation (Mississippian to Pennsylvanian)**—Tan quartz arenite with 0.5 to 1 m thick tabular interbeds of limestone and dolostone. Near fault zones the unit is poorly exposed and recessive. Tabular beds occasionally have planar crossbedding and flat laminations, with heavily bioturbated tops, including ~ 2 cm diameter horizontal and vertical burrows. Fossil assemblage includes inarticulate *orbiculoidea* brachiopods, rugose corals, bryozoa, crinoids, and articulate brachiopods. Irregular quartz, calcite, and minor dolomite cement results in pock-mark weathering and splotchy, nodular, or honeycomb appearance. Fine to medium quartz sand grains are subrounded to rounded with moderate sorting. Sharp lower contact with Railroad Canyon Formation. Gradational contact with overlying Snaky Canyon Formation was mapped where carbonate beds outnumber sandstone beds. Fossiliferous near the top. Correlative with the type Bluebird Mountain Formation in the southern Beaverhead Mountains (Skipp and others, 1979) and the lowermost Quadrant Formation of Lucchitta (1966). Poorly constrained thickness of ~60 m (195 ft), based on measured section ~ 20 km (12 mi) to the southeast, near Morrison Lake, MT (Lucchitta, 1966).

Mr **Railroad Canyon Formation (Mississippian)**—Gray siltstone, black papery shale, orange- to gray- weathering banded lime mudstone and siltstone, with rare wackestone, packstone, and grainstone. Poorly exposed, except at the type section south of Hood Gulch, ~1.5 km (1 mi) north of the map area (Wardlaw and Pecora, 1985; Ruppel and Lopez, 1988; Batt and others, 2008). Forms low-relief slopes with lavender-weathering chippy, often silicified and deformed float. Shows association with landslide deposits. Lower contact is sharp, marked by abundant, chippy shales and siltstones with mm-scale layering. Middle portion contains distinctly banded 10-30 cm tabular beds of massive gray-weathering lime mudstone and finely laminated orange weathering carbonaceous siltstone. Upper portion contains chert, carbonate grainstone with heterolithic clasts, and shale. Upper contact with Bluebird Mountain Formation is sharp. Correlative to "Big Snowy Formation basal siltstone and shale" and "upper Big Snowy/Railroad Canyon Formation" of Lonn and others (2019). Measured thicknesses at the neighboring type section varies from 205 m (670 ft, Wardlaw and Pecora, 1985), to 260 m (850 ft, Ruppel and Lopez, 1988), to 320 m (1050 ft, Batt, 2006). Variability in measured thicknesses is likely due to previously unrecognized normal faults that occur in the vicinity of the type section (Lonn and others, 2019).

Msp **Scott Peak Formation (Mississippian)**—Dark- to light-gray weathering fossiliferous wackestone and packstone with lesser lime mudstone containing chert. Resistant tabular to massive beds ranging from 0.5 to 2 m in scale, form cliffs in steep canyon walls. Rare crossbedding in lenticular beds of encrinites with sharp top and bottom contacts. Uncommon beds of nodular, sometimes wood-grained chert. Common fossils include crinoid stem fragments (up to 1 cm in diameter), brachiopods, bryozoa, and corals (including rugose and lithostrotion). Gradational lower contact with the Middle Canyon Formation, marked at the first occurrence of resistant, fossiliferous limestone beds. Sharp upper contact with Railroad Canyon Formation, marked by shale overlying thick-bedded tabular wackestone containing large (up to 15 cm long) caninid corals. Tabular, resistant beds often exhibit 1-5 m wavelength detachment-style folds. Correlative to "Upper Madison Limestone" of Ruppel (1968), and "Mission Canyon Formation" of Lucchitta (1966) and Huh (1967). Thickness of unit is poorly constrained in map area. At least 400 m (1300 ft) is exposed in the northwest part of the map area (comparable with 380 m (1245 ft) in the southern Beaverhead Mountains. The unit is twice as thick, 850 m (2790 ft) at the type locality in the southern Lemhi Range (Huh, 1967).

Mmc **Middle Canyon Formation (Mississippian)**—Dark-gray to black, silty lime mudstone with bedded chert and sparse dolostone. Tabular beds range from ~5- 20 cm thick. Tan- to gray-weathering, recessive and slope-forming. Chert ranges from cm-scale layering, to 10-20 cm thick undulating, sometimes discontinuous beds, to dm-scale isolated nodules. Uncommon silt to shale interbeds, particularly within ~ 20 m of the base of the section. Rare crinoid-bearing wackestone and wood-grained chert. Gradational lower contact marked by first bedded chert and limestone bed, observable just off the northwest part of the map area (Lonn and others, 2019). Gradational upper contact is obscured, approximated by the first occurrence of resistant, fossiliferous wackestone bed on the meter-scale. Contains 10s of meters of jasperoid (calcite replaced by silica) on the western side of Jakes Canyon. Correlative to "Lower Madison Limestone" of Ruppel (1968), "Lodgepole Formation" of Lucchitta (1966) and Huh (1967), and "Middle Canyon Formation" of Huh (1967) and Mamet et al. (1971). Estimated thickness of ~ 200 m (560 ft) near the Digmore mine (Lonn and others, 2019), is comparable with measured thicknesses of 250 m (820 ft) at Lake Canyon, MT, ~15 km (9 mi) to the northeast (Huh, 1967), and 210 m (690 ft) in the Hawley Mountains (Mamet and others, 1971).

Mmg **McGowan Creek Formation (Mississippian)**—Black to dark-gray and light-gray siltstone and claystone and gray- to tan-weathering silty lime mudstone and lime mudstone. Bedding ranges from mm-scale laminations to tabular, decimeter-scale beds. Recessive, slope-forming unit, distinguished by abundant chippy siltstone and claystone float. Calcite cement common, with rare dolomite cement. Bottom and top are mostly siliciclastic, while middle contains more carbonate, including a lavender-weathering lime wackestone bed of a few meters thickness. Sharp bottom contact. Gradational upper contact is placed below first occurrence of bedded chert. Correlative to "Milligen Formation" of Huh (1967), "Milligen(?) and Three Forks Formations" of Ruppel (1968), "Three Forks" of Lucchitta (1966), and "Trident member of the Three Forks Formation", "Lower Sappington", and "McGowan Creek Formation" of Grader and others (2016). May correlate with transgressive systems tract above the "Trident Member flooding surface" of Grader and others (2016). Thickness of 28 m (92 ft), measured at a full section in the head of Jakes Canyon, ~0.75 km (0.5 mi) north of the map area.

Dj Jefferson Formation (Devonian)— Dark- to light-gray dolomitic mudstone, fossiliferous wackestone, and minor tan-weathering quartz arenite. Tabular bedding ranges in thickness from ~0.5 m to 3 m, occasionally with calcite vugs at the top. Recessive weathering slope former, with isolated resistant beds. Fetid odor on freshly broken surfaces. Flat to wavy (algal?) laminations on mm-scale are common. Rare rip-up clasts, minor scour pits, and ooids. Distinctive, fossiliferous sections exposed on the Baby Joe Gulch thrust hanging wall. Exposures outside of the Baby Joe Gulch thrust hanging wall consist of a thinner section of almost entirely unfossiliferous dolomite mudstone with fine laminations. Exposures of the Baby Joe Gulch thrust hanging wall contain a lower unit of unfossiliferous dolomite mudstone with fine laminations and an upper unit with abundant dolomitic wackestone containing bivalves, brachiopods, crinoids, *stromatoporoidea* (possibly including *actinostroma*) and distinct beds of large (cm-scale width) *cladopora* overlain by smaller (mm-scale width) *amphipora*. Everywhere observed, the bottom contact is sharp and marked by a tan-weathering quartz arenite. The basal sandstone contains well-sorted, well-rounded fine quartz sand with partly dolomitic and quartz cement which vary laterally. Rare crossbeds fill apparent ~1 m deep channels. Lower contact is everywhere unconformable. Upper contact is not observed on the Baby Joe Gulch thrust plate, but is sharp when observed elsewhere. Section exposed below the Baby Joe Gulch thrust is ~50 m (165 ft) thick and is likely Famennian in age (Scholten and Hait, 1962; Grader and others, 2016); ~150 m (490 ft) are exposed above the Baby Joe Gulch thrust and is likely Frasnian to Famennian in age.

SOs **Saturday Mountain Formation (Lower Silurian to Middle Ordovician)**—Splotchy, light- to dark-gray dolo-wackestone and bleached gray crystalline dolostone. Tabular beds are decimeter to 2 m thick. Cliff-forming unit, predominantly exposed near Railroad Canyon. Cyclical light to dark layering at meter-scale is visible from a distance. Distinct mottled texture with occasional graded beds and laminations. Abundant fossils in the lower and middle portion, including: horn coral, *favosites*, *halysites*, crinoids, and brachiopods. Bottom contact is sharp with the Kinnikinic Quartzite. Exposed only in the Baby Joe Gulch thrust hanging wall. Upper contact is below a thin bed of sandstone of the Jefferson Formation. Correlative to Laketown Dolomite and Saturday Mountain Formation (Lucchitta, 1966; Ruppel, 1968; Ruppel and Lopez, 1988; Evans and Green, 2003; Lund, 2018). Approximate thickness of 90 m (295 ft), based on exposures just west of Italian Gulch. A comparable thickness of ~160 m (525 ft) is exposed near Leadore Hill, ~15 km (9 mi) south of the map area.

Ok **Kinnikinic Quartzite (Middle Ordovician)**—Vitreous white quartzite with grain boundaries not visible. Unit contains meter-scale beds. Unit forms talus slopes and resistant cliffs. In some places, imperfect distribution of quartz cement results in brown spots that weather into prominent pock marks. Commonly brecciated with orange-weathering siliceous matrix. Rare crossbeds with bioturbated tops including vertical burrows. Lower contact with the Beaverhead pluton is inferred to be nonconformable (Link and others, 2017), but is not exposed. Unit is exposed only in the Italian Gulch thrust hanging wall. Apparent thickness of ~ 140 m (460 ft) based on exposure east of Railroad Canyon.

PALEOZOIC INTRUSIVE ROCKS

OCi **Felsic alkaline intrusions (Ordovician to Cambrian)**—Pink to red, alkali feldspar syenite and granite, and minor greenish-black diorite and gabbro. Recessive weathering, forming brownish-red slopes. Medium- to coarse-grained and rarely foliated. Exposed in Baby Joe Gulch thrust hanging wall. Correlative with 500-485 Ma (U-Pb zircon; Lund and others, 2010) Beaverhead pluton of Scholten and Ramspott (1968). Kinnikinic Quartzite overlies these intrusive rocks with an erosional contact as has been documented ~30 km (20 mi) to the southeast (Link et al., 2017).

CAMBRIAN TO MESOPROTEROZOIC STRATA

€Ygh **Quartzite of Grizzly Hill (Cambrian to Mesoproterozoic?)**—Gray to green, fine-grained quartzite with minor silt. Tabular 10-50 cm beds with lateral thickness changes apparent over 10s of meters. Recessive-weathering, primarily forming slopes with rare outcrops. Common flat laminations and rare trough crossbeds, mud chips, graded beds, and ripples. Fine-grained quartz sand with visible grain boundaries and abundant mica. Sub-rounded to rounded, predominantly quartz grains supported by a muddy matrix. Bottom contact not observed. Upper unit consists of 20-30 m of vitreous medium- to coarse-grained white quartzite with massive beds on the meter scale. Lower contact of upper unit is gradational. An upper bed of 1-3 m of quartzite pebble to boulder conglomerate is observed in several locations (Fig. 5). Clasts are well rounded and matrix supported. Upper contact with Jefferson Formation is disconformable near Radio Tower Hill in southwestern part of map area, but strongly angular near Grizzly Hill ~ 4 km (2.5 mi) to the north, where the restored unconformity dips 20° to the northeast. Age is uncertain. Possible trace fossils and burrows (Lonn and others, 2019) suggest a tentative correlation with Cambrian/Neoproterozoic quartzites in southwestern Montana (Lonn and Lewis, 2012; McDonald and Yakovlev, 2019). Alternatively, may correlate to the Jahnke Lake Member of the Apple Creek Formation (Burmester and others, 2016). Apparent thickness exceeds ~250-300 m (820-985 ft) on Radio Tower hill.

STRUCTURAL GEOLOGY

The northernmost part of the map area is defined by ~1800 m (6000 ft) of Paleozoic sedimentary rocks that form a conformable, southeast-dipping panel. These rocks were folded by open to tight, 5-10 m wavelength, detachment-style folds that plunge gently to the southeast. These folds are best observed in the Msp, Mr, and Psc units, particularly in the northwestern and northern part of the map area. Fold asymmetry and kinematic indicators suggest top-to-the-northeast displacement along bedding surfaces. Bedding and fold hinges were both similarly tilted toward the southeast prior to burial beneath a carbonate mylonite that characterizes the base of a later, structurally higher thrust system that we call the Thompson Gulch thrust. Beneath the Thompson Gulch thrust, the sedimentary rocks locally exhibit a pervasive low-angle pressure solution cleavage. This pressure solution cleavage accommodated up to ~50% sub-vertical coaxial flattening as constrained by measurements of strained rugose corals and is interpreted to have formed during footwall burial beneath the overlying thrust system.

In the central and southern parts of the map area, mylonite occurs at two structural positions: above the relatively undeformed upper Paleozoic dip panel and above the lower Paleozoic intrusive and sedimentary rocks in the hanging walls of mapped thrusts near the range front. After mylonitization, mylonites in both structural positions were folded about WNW-ESE and WSW-ENE trending folds and truncated by several, generally south-dipping thrust faults (see below). Secondary silicification of brecciated mylonite is commonly observed, most notably in Jakes Canyon.

THOMPSON GULCH THRUST

Lund (2018) designated "greenschist-facies, isoclinally folded, marble phyllite" as a "tectonite" in the hanging wall of the Thompson Gulch thrust. Our work builds upon Lund's (2018) work. Our field mapping reveals that this tectonite exhibits a strong foliation and prominent stretching lineation (Fig. 1); we thus refer to these rocks as mylonites. Mylonites defining the base of the Thompson Gulch thrust sheet occur structurally above the Paleozoic dip panel in the northern part of the map area and generally armor ridgelines in a continuous panel. The base of this mylonite cuts up section toward the east and dips gently to the southeast. The stretching lineation in the mylonite is well-developed, sub-horizontal, and roughly east-west trending (Fig. 3). Rare crinoid ossicles in the mylonite exhibit up to 30% stretching in a direction parallel to the stretching lineation. Syn-kinematic isoclinal and sheath fold hinges are loosely sub-parallel to the east-west stretching lineation. Mylonites also occur in the southwestern part of the map area, where they are subparallel to and on top of basal Devonian strata that unconformably overlie the Quartzite of Grizzly Hill. The relationship between this mylonite and the Thompson Gulch thrust is uncertain. Mylonites that define the Thompson Gulch thrust were folded by alternately trending WNW-ESE and NE-SW folds after mylonitization. Mylonites of the Thompson Gulch thrust are also truncated by the Baby Joe Gulch and Radio Tower thrusts at Thompson Gulch, and the Italian Gulch thrust on the western side of Italian Gulch.

ITALIAN GULCH THRUST

We define the Italian Gulch thrust in the south-central and eastern part of the map area. This thrust dips moderately to the SSE and juxtaposed a hanging wall of Beaverhead pluton, Kinnikinic Quartzite, Saturday Mountain Formation, Jefferson Formation, and mylonite with a footwall of Snaky Canyon Formation and its structurally overlying Thompson Gulch thrust mylonite. Notably, the Kinnikinic Quartzite and Saturday Mountain Formation are not present beneath the subjacent Thompson Gulch thrust's footwall, which demonstrates substantial pre-thrusting stratigraphic complexities in the region. The Italian Gulch thrust is structurally overlain by the Railroad Canyon thrust and an isolated thrust with minor stratigraphic offset, that carried Kinnikinic Quartzite at the southern range front near Railroad Canyon. The relationship between the Italian Gulch and Baby Joe Gulch thrusts is unclear, as the two are apparently mutually crosscutting. Folds in the proximal hanging wall and footwall of the Italian Gulch thrust are WSW-ENE trending.

BABY JOE GULCH THRUST

Lund (2018) defined the Baby Joe Gulch thrust as carrying a hanging wall of Cambrian plutonic rock and Ordovician to Devonian sedimentary strata. We apply the same usage, though our interpretations differ significantly from Lund's (2018) in the southeastern part of the map area. The Baby Joe Gulch thrust is planar for most of its trace, from Jakes Canyon to Italian Gulch. Though poorly exposed, our mapping constrains a dip to the south-southwest at 30-40°, with parallel foliation developed within the pluton. In and west of Thompson Gulch, the Baby Joe Gulch thrust clearly cut the Thompson Gulch thrust and associated mylonite. These rocks in the immediate footwall of the Baby Joe Gulch thrust exhibit a foliation that dips more shallowly to the west-southwest than constrained for the Baby Joe Gulch thrust, which suggests the presence of a footwall ramp. East of Italian Gulch, the trace of the Baby Joe Gulch thrust curves to the northeast and then appears to be truncated by the Railroad Canyon thrust. In several places, the Beaverhead pluton rocks in the hanging wall of the Baby Joe Gulch thrust are structurally overlain by calcareous mylonite. Sense of slip is unclear. Top-to-NW sense of slip was interpreted in the immediate footwall on the western side of Jakes Canyon. Top-to-NE sense of slip was interpreted in the immediate footwall on the eastern side of Jakes Canyon.

RAILROAD CANYON THRUST

We define the Railroad Canyon thrust on the western side of Railroad Canyon, in the southeastern part of the map area. This thrust dips moderately to the SE, and juxtaposes an intact section of Saturday Mountain and Jefferson Formation in its hanging wall with a thick carbonate mylonite in its footwall. Well-defined stretching lineations in the mylonite are ~ E-W oriented, parallel to stretching lineations in the mylonite beneath the Thompson Gulch thrust. The footwall mylonite lies above the Beaverhead pluton, visible in rare outcrops in Italian Gulch, Baby Joe Gulch, and Jakes Canyon. The relationship between mylonites of the Railroad Canyon thrust, the Thompson Gulch thrust, and the mylonites in the hanging wall of the Radio Tower thrust is unclear. The initially low-angle, likely flat on flat fault surface appears folded, based on the map pattern and attitudes from the mylonite. It also appears to be cut by the higher-angle, basement-involved Baby Joe Gulch and Italian Gulch thrusts. A well-exposed WNW-ESE trending hanging wall syncline is observable on the eastern side of Railroad Canyon, just below an unnamed thrust that carries Kinnikinic Quartzite in its hanging wall.

RADIO TOWER THRUST

We define the Radio Tower thrust on the western side of Jakes Canyon, in the southwestern part of the map area. Here, the thrust dips steeply to the south, placing a ramp of the Quartzite of Grizzly Hill overtop a ramp of Paleozoic carbonates that are sometimes heavily silicified. Resistant cliffs in the immediate footwall on the western side of Jakes Canyon resemble jasperoid, and are composed of silicified breccias containing mylonite clasts. In Thompson Gulch, a low-angle thrust that placed dolostones of the Jefferson Formation on top of mylonites of the Thompson Gulch thrust can be followed to the NW. The two exposures differ in fault orientations and apparent structural styles and are separated by an area of limited exposure, raising significant uncertainty about the geometry and kinematics of this fault. In both localities, the Radio Tower thrust cuts footwall mylonites of the Thompson Gulch thrust at a low-angle. Hanging wall rocks are folded about ~NE-SW and WNW-ESE trending folds.

UNNAMED NORMAL FAULTS

Two generations of normal faults were identified. The older set strikes NNW to NW and dips both directions at a high angle. These structures generally exhibit displacements of less than 100 m, but are crucial for understanding the apparent changing structural positions of the older thrusts. The largest mapped normal fault of this set can be traced from Leadville at the range front to near the Digmore Mine in the Bannock quadrangle ~2.5 km (1.5 mi) to the north of the map area. It is unclear whether the large, west-side-down normal fault in Cedar Gulch belongs to this set. These faults may be related to the development of the Miocene basin containing Renova and Six Mile Creek formations in Railroad Canyon of the Bannock Pass quadrangle (Fields and others, 1985).

BEAVERHEAD FAULT SYSTEM

Normal faults related to the modern range front cut the previously described set of unnamed, older normal faults, and offset surficial deposits in places. Prominent scarps are most obvious in the eastern part of the map area, where the trace of the Beaverhead fault changes from ~ESE-WNW to ~N-S.

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