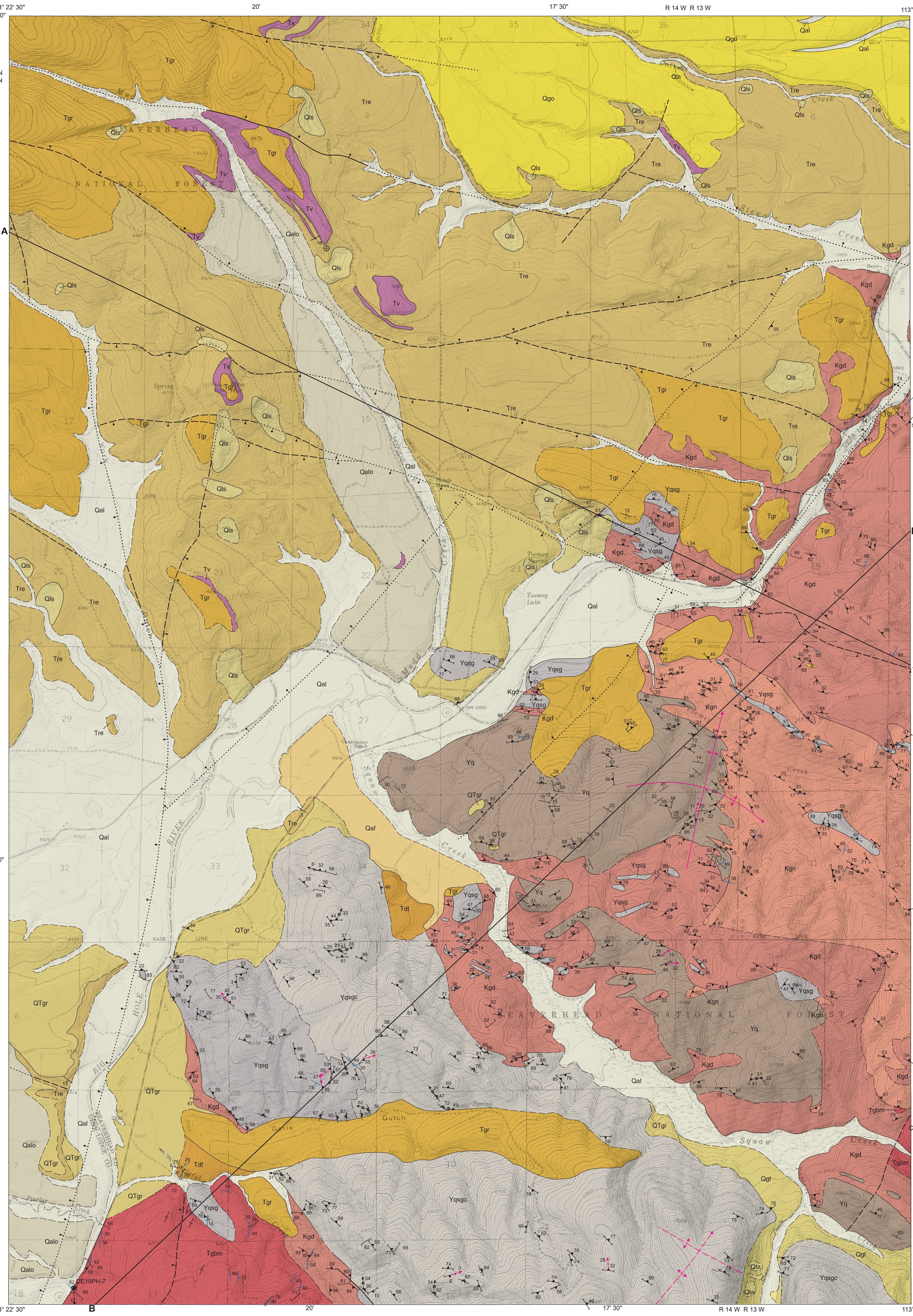


Pine Hill 1:24,000-scale quadrangle map
Base map produced by the United States Geological Survey 1962
Revised by USDA Forest Service 1997
Topography compiled 1955. Planimetry derived from imagery taken 1995 and other sources. Public Land Survey System and survey control current as of 1999.
Horizontal Datum: 1927 North American Datum
Projection: Lambert Conformal Conic
Grid:1000 meter Universal Transverse Mercator Zone 12
Vertical Datum: National Geodetic Vertical Datum of 1929

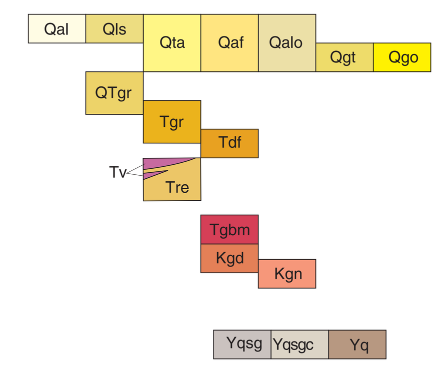
Shaded relief created from 10 meter digital elevation model from U.S. Geological Survey National Elevation Dataset.

Utm grid and 2017 magnetic north declination at center of sheet

SCALE 1:24,000
CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

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

CORRELATION DIAGRAM



MAP SYMBOLS

- Contact: dashed where approximately located
- Fault: dashed where approximately located, dotted where concealed
- Normal fault: dashed where approximately located, dotted where concealed, bar and ball on downthrown side
- Plunging antiform, arrowhead shows direction of plunge
- Inclined beds, showing strike and dip
- Dikes, showing strike and dip
- Horizontal bedding
- Preferred orientation foliation, showing strike and dip
- Spaced cleavage, showing strike and dip
- Inclined cleavage, showing strike and dip
- Mylonitic foliation with stretching lineation, showing strike and dip
- Gneissosity, showing strike and dip
- Gneissosity with intersection lineation, showing strike and dip
- Gneissosity with mineral lineation, showing strike and dip
- Axis of minor fold or crenulations with plunge
- Geochronology sample locations (Note: sample CE19-PH11a was collected just off the east edge of the map)

Introduction

The Pine Hill 7.5′-quadrangle bridges the westernmost Western Pioneer Range and the Big Hole River Valley, and is part of the Wisdom 30′ x 60′ quadrangle. The Pine Hill geologic map builds on previous work by Hanneman (1987), and on recent detailed mapping in the east-adjacent Foolhen Mountain 7.5′ quadrangle (Elliott and Lonn, 2021). Though the entire 7.5′ quadrangle is included here, detailed mapping focused on the south half, as does the explanation below.

The Pine Hill 7.5′ quadrangle is part of the Dillon 1° x 2° quadrangle mapped by Ruppel and others (1993) at a scale of 1:250,000. The Pine Hill map contributes to filling in the Wisdom 30′ x 60′ quadrangle and meeting the long-term MBMG-STATEMAP goal to completely map all of Montana at a scale of 1:100,000.

Regional Setting

The rolling mountains of the southeastern half of the map area are underlain by high-strain, high-grade metamorphic rocks in the Grasshopper Plate of the Cordilleran fold-thrust belt (Ruppel and Lopez, 1984). The Grasshopper Plate is the uppermost and westernmost thrust sheet formed by Cretaceous through Paleocene ductile Cordilleran contraction of Mesoproterozoic through Late Cretaceous sedimentary and granitic rocks. The northwestern half of the quadrangle is covered by Paleogene and Neogene strata of the Big Hole basin. The entire Pine Hill quadrangle lies above the shallowly southeast-dipping Anaconda Detachment that separates the footwall and hangingwall of the Anaconda Metamorphic Core Complex (AMCC, fig 1) (O'Neill and others, 2004). Drill hole and geophysical data for the Big Hole Basin indicate that the Anaconda Detachment is buried under as much as 2,000 m (6,600 ft) of Paleogene through Quaternary deposits in the northwest half of the Pine Hill quadrangle (Roe, 2010).

Geologic Summary

The crystalline rocks of the Pine Hill quadrangle are closely intermixed, and appear to be part of a mid-crustal high-strain zone. The oldest are feldspathic quartzites of the Mesoproterozoic Lemhi subbasin of the Belt Supergroup (Yq). Other metasedimentary rocks in the quadrangle (Yqsg and Yqsgc, fig. 2) also probably had Mesoproterozoic protoliths, though some may be Phanerozoic, like some in the east-adjacent Foolhen Mountain quadrangle (Truckle, 1988; Elliott and Lonn, 2021); however, metamorphism and intense deformation make stratigraphic correlation tenuous.

Igneous intrusion at about 72–74 Ma coincided with deformation and metamorphism. Evidence for this includes overlapping U-Pb zircon ages for granodiorite and gneiss in the adjacent Foolhen Mountain 7.5′ quadrangle (Elliott and Lonn, 2021), and the smooth transition between unfoliated and gneissic within Kgd, suggesting that part of the pluton was undergoing solid-state deformation while other parts underwent submagmatic flow. At Chalk Bluff, near the center of the quadrangle (fig. 1), Kgd ranges from massive to intensely gneissic and sheared (figs. 3a, 3b) over the 200 m (660 ft) between the highway and the contact with metasedimentary rocks (Yqsg). A similar transition occurs east of the Big Hole River where, from north to south, massive Kgd becomes increasingly foliated and gneissic until it transitions into Kgn.

The east–southeast-trending, north–northeast-inclined structural fabric of the crystalline rocks in the Pine Hill quadrangle is defined by both lithology and strain variation. The southeast-trending bands of Kgn and Yqsg are highly strained gneisses and migmatites that contain no identifiable primary structures. Near the center of the quadrangle, however, Yq retains bedding and other primary structures, possibly because formation of gneissic layering was inhibited by the lack of phyllosilicates. Yq is intruded by Kgd, and in the middle of the quadrangle forms the core of a shallowly east-plunging antiform that folds a preferred dimensional foliation in Kgd (S_1), which is parallel to the Yq–Kgd contact. Another, stronger, preferred orientation fabric and locally developed gneissosity (S_2) parallels the axial surface of the fold. The axial surface is itself gently folded across a north-striking axial plane (F_3).

The structural style is the same within Yqsg metasediments in the south of the Pine Hill quadrangle. In the south-adjacent Proposal Rock 7.5′ quadrangle and along the southern edge of the quadrangle, outcrop scale M-folds with north–northeast-trending axial surfaces overprint east–southeast-trending isoclines. These overprinting relationships mirror that found at higher structural levels of the Grasshopper Plate, to the northeast of Pine Hill, where folds in Proterozoic through Cretaceous strata reflect a change from northeast–southwest to east–west shortening during orogenesis (Elliott, 2017).

The Tertiary strata in the Pine Hill quadrangle are not well exposed, and are mapped mostly by float and soil characteristics, and using a lidar hillshade obtained from the Montana State Library Lidar Inventory. The Renova Formation (Tre, fig. 4) and interlayered mafic flows (Tv) were deposited during Eocene through Oligocene extension on the Anaconda Detachment (Foster and others, 2010), though extension may have continued into Miocene times (Elliott and Lonn, in review). Subsidence and deposition of fluvial (fig. 5) and lacustrine sediments in the Big Hole Valley continued through Miocene times that ultimately created a sedimentary basin over 4,870 m (16,000 ft) deep, and as much as 2,000 m (6,600 ft) deep within the Pine Hill quadrangle (Roe, 2010).

Basin formation and subsidence was achieved by movement on the east–southeast-, north–northeast-, and north-trending faults shown on the northwestern half of the map. The relative ages of the faults are not clear, but the youngest fault identified in the quadrangle is within the Big Hole River plain where a low east–northeast-trending scarp that cuts recent sediments is visible on the lidar hillshade. There may be other Quaternary faults, but no other Quaternary scarps have been found.

Tertiary gravels cover bedrock benches on the southeast side of the Big Hole River, and form a linear ridge along Gorris Gulch that reaches an elevation of nearly 2,100 m (6,850 ft). This is more than 900 ft above the Big Hole River flood plain, and higher than any other Tertiary strata exposed in the map area and perhaps the entire West Pioneer Range. Maybe the pre-Tertiary rocks in the Pine Hill quad were once buried by sediments that are now eroded away.

The youngest deposits in the area are Quaternary glacial deposits and talus piles in the southeast corner of the map, and deposits associated with modern or abandoned streambeds and floodplains along the Big Hole River and tributary drainages.

Description of Map Units

Qal **Alluvium (Holocene)**—Modern stream and floodplain deposits, including gravel, sand, silt, and clay in stream channels and floodplains. Thickness as much as 10 m (33 ft).

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

Qgt **Glacial till (Pleistocene)**—Unsorted clay to boulder deposits in lateral, ground, and medial moraines. Characterized by hummocky terrain scattered with large subangular to subrounded boulders. Thickness may be as much as 36 m (120 ft).

Qgo **Glacial outwash (Pleistocene)**—Moderately to well sorted, subrounded to well-rounded gravel and sand sheets immediately downslope from glacial deposits. Deposits are typically incised by younger alluvium. Thickness 2–10 m (9–33 ft).

Qta **Talus (Holocene–Pleistocene)**—Angular and subangular cobble- to boulder-size clasts at the base of steep valley walls or cliffs. Thickness probably less than 10 m (33 ft).

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

Qalo **Alluvium, older (Pleistocene)**— Moderately to well-sorted cobble gravel, sand, and silt in stream and flood plain deposits above the modern flood plain. Forms dissected terraces. Thickness 2–10 m (9–33 ft).

QTgr **Gravel (Miocene?–Holocene?)**—Cobble and boulder lag deposits on benches. Clasts are dominantly well-rounded quartzite, but include local igneous ad metamorphic rock types. Gravel lag covers all Tertiary sediments except where fresh cuts and actively eroding surfaces expose ashy Tre. QTgr is shown where lag is thought to be more than 1 m thick. QGtr is 10 m (32 ft) thick in a stock well at the southwest corner of the map (N45.772421° W113.374341°: T. 1 S., R. 14 W., sec 6, SW1/4, SE1/4).

Tgr **Gravel (Miocene)**—Cobble and boulder gravel with matrix of sand and silt. Clasts are sub-rounded to well-rounded, with low sphericity, and commonly have tan weathering rinds (fig. 5). Clasts are mostly granite and metamorphic rock types, dominated by quartzite. Tgr is not well exposed, but is characterized by smooth rounded topographic surfaces. Roe (2010) describes lateral equivalents of Tgr as laterally and vertically variable, with channels of sand and gravel interlayered with thinly bedded, finer sediments. Correlates with Sixmile Creek Formation. Miocene age comes from tentative fossil identifications and detrital zircon spectra that indicate a minimum age of 11.6 Ma (Roe, 2010). Thought to be up to 60 m (200 ft) thick.

Tdf **Debris flows (Miocene)**—Boulder and cobble gravel with unsorted, angular to well-rounded clasts up to 2 m (6 ft) across. Angular clasts dominated by local rock types, and rounded clasts dominated by quartzite. Only two exposures, both in the south half of the Pine Hill quadrangle. May correlate with the Sweetwater Member of the Sixmile Creek Formation as described by Fritz and Sears (1993).

Tv **Volcanic rocks (Oligocene)**—Dark gray vesicular basalt with olivine and plagioclase phenocrysts, and brown to gray welded tuff. Fritz and others (2007) describe these rocks as basanites—i.e., low silica, low alkali, foid-bearing mafic extrusive rocks. In the north edge of the Pine Hill quadrangle there are two prominent sets of flows interlayered with the top of Tre. Fritz and others (2007) report a K-Ar age of 21.9 ± 0.3 Ma for one of these flows at T. 2 N., R. 14 W., sec 34, SW1/4, SW1/4 [Fritz and others, 2007 (UTM coordinates 12T 319640E 5079381N)]. They include Tv in the upper Dillon Volcanics. Current mapping indicates that the flow that Fritz and others (2007) sampled is near the base of the volcanic sequence. Flows up to 30 m (100 ft) thick.

Tre **Renova Formation (Oligocene)**—Poorly exposed white, gray, and orange ashy sand, silt, and clay with rare gravel lenses (fig. 4). Olive green, brown, and gold when wet. Contains gray paleosols near top, and ochre to maroon Liesegang banding. Clay intervals weather with a popcorn texture that is typical of the Renova Formation. At Chalk Bluff, a single tooth fragment was tentatively dated as Oligocene (Hanneman and Nichols, 1981; Roe, 2010). At a related section northeast of the Pine Hill quadrangle, Roe (2010) got a U-Pb zircon igneous age of 29.597 ± 0.008 Ma from a tuff at the base of the exposed sequence. Thickness more than 100 m (330 ft).

Tgbm **Biotite–muscovite granite (Paleocene–Oligocene?)**—Medium- to coarse-grained, porphyritic, biotite-muscovite granite. Light gray to very pale pink. Exposed on the east side, and southwest corner of the Pine Hill quadrangle. In the adjacent Foolhen Mountain quadrangle (Elliott and Lonn, 2021), Tgbm is mostly massive to weakly foliated, but forms inclusions in Yqsg that are massive to strongly deformed, and gneissic Tgbm is the Bryant Creek granite of Truckle (1988) and TKg of Ruppel and others (1993).

Tgbm in the southwest part of the Pine Hill quadrangle is part of the Doolittle Creek Pluton, a fine-grained Kspar–plagioclase–biotite to biotite–muscovite granite and granodiorite densely intruded aplite dikes and sills and associated milky quartz veins. Generally porphyritic, non-foliated to weakly foliated. Is described as biotite granite to granodiorite by Berger and others (1983) but included in a biotite–muscovite granite suite by Ruppel and others (1993). Snee (1982) includes it in a "Late Group" of biotite granodiorite and tonalite plutons of the Pioneer Batholith.

Two-mica granites in the region have crystallization and cooling ages that vary between about 65 and 39 Ma (Snee, 1982; Desmarais, 1983; Zen, 1988; Wallace and others, 1992; Ruppel and others, 1993; Foster and others, 2007, 2010; Howlett and others, 2020). Ruppel and others (1993) correlate Tgbm with the Clifford Creek Granite of Zen (1988), who reports 64.6 ± 2.1 Ma and 64.9 ± 2.2 Ma K-Ar ages for biotite and an $^{40}Ar/^{39}Ar$ age of 65.6 ± 1.4 Ma. Snee (1982) reports a muscovite cooling age of 63.9 ± 0.8 Ma and a biotite cooling age of 61.3 ± 0.6 Ma for a small two-mica pluton in the adjacent Proposal Rock quadrangle. Snee (1982) prefers an emplacement age of about 65 Ma but acknowledges that it could be as old as 72 Ma. For this study a U-Pb zircon age of 62.08 ± 0.8 Ma was determined for Tgbm just off the east side of the Pine Hill quadrangle (CE19PH-11a), and 68.2 ± 0.8 for the Doolittle Creek Pluton (CE19PH-7).

Kgd **Granodiorite, unfoliated and foliated (Cretaceous)**—Gray, medium- to coarse-grained granular to porphyritic granodiorite and tonalite named the Nichols granodiorite where it is exposed at Chalk Bluff (Roe, 2010), though it is part of the Foolhen Mountain Pluton (Elliott and Lonn, 2021). Containing 5–35 percent biotite, hornblende, or both biotite and hornblende and 5–56 percent potassium feldspar (Truckle, 1988). Hornblende appears to increase in abundance towards the south and west. Mafic inclusions abundant. Varies from massive with no foliation, to weakly foliated (preferred dimensional orientation fabric), to strongly gneissic, particularly near contacts with Yqsg (fig. 3). At Chalk Bluff, Kgd is massive at the bottom of the hill but grades to strongly gneissic at the contact with Kgn metasedimentary rocks. The contact is not parallel to gneissosity, suggesting that it is tightly folded and that the compositional layering is axial planar to the folds. Alternately, it is possible that the metasedimentary rocks and granodiorite were interleaved before deformation. Contains light gray, fine-grained aplite dikes with up to 15 percent plagioclase and 5 percent biotite. Also contains metasedimentary inclusions of all sizes, from hand sample to map scale. Roe (2010) obtained a U-Pb zircon age of 71.8 ± 2.0 Ma for a sample from Chalk Bluff. Zircons from a biotite-rich, unfoliated sample of Kgd from the adjacent Foolhen Mountain quadrangle yield a U-Pb zircon age of 73.89 ± 0.39 Ma (Elliott and Lonn, 2021).

Kgn **Gneiss complex (Cretaceous)**—Quartz–feldspar–biotite–hornblende gneiss that reflects a granitic protolith mixed with quartz–feldspar–biotite–cordierite metasedimentary gneiss. Typically gray, very fine-grained, and intensely foliated, with mylonitic zones and evidence of transposition. Locally strongly lineated. Equivalent to Foolhen Gneiss of Berger and others (1983). In the adjacent Foolhen Mountain quadrangle, Elliott and Lonn (2021) obtained a zircon age of 73.24 ± 0.40 Ma. Metasedimentary protoliths are uncertain, and could be any age from Mesoproterozoic to Mesozoic. Kgn is equivalent to Xm of Berger and others (1983), who interpreted the unit to be Paleoproterozoic basement gneiss. Ruppel and others (1993) reinterpreted the unit as metamorphosed Cretaceous igneous rock.

Yqsg **Quartzite, schist, and migmatite gneiss (Mesoproterozoic: Cretaceous metamorphic age)**—Fine- to medium-grained amphibolite–facies quartz–potassium feldspar–plagioclase–muscovite–biotite–sillimanite metasedimentary gneiss and schist that is commonly migmatitic. Exposures along the Big Hole River are deeply weathered and quartz-rich. Migmatite neosome is fine- to medium-grained biotite–muscovite granite locally injected or segregated in foliation-parallel sheets (lit-par-lit), as blobs in fold hinges, or parallel to the axial plane of folds. Yqsg is complexly deformed, with several fold generations. Gneissosity shown on map is mostly a transposition foliation and is the most recent fabric. Mapped by Truckle (1988) and Berger and others (1983) as Paleoproterozoic metamorphic rock, but as metamorphosed Mesoproterozoic Belt Supergroup by Ruppel and others (1993). Elliott and Lonn (2021) obtained detrital zircon spectra that support this Belt protolith interpretation.

Yqsgc **Coarse-grained varient of Yqsg (Mesoproterozoic: Cretaceous metamorphic age)**—Quartzite, schist, and migmatite gneiss. Locally similar to Yq, with remnant bedding in places, but is generally more pelitic and more strongly deformed (fig. 2). Possible lateral equivalent of Yqa quartzite and argillite of Lonn (2020).

Yq **Quartzite, Belt Supergroup (Mesoproterozoic)**—Coarse-grained, flat-laminated to cross-bedded feldspathic quartzite, gray to maroon, upright wherever primary structures observed. Contains up to 10 percent potassium feldspar, flakes of muscovite, biotite segregations defining beds and cross-beds, and locally centimeter-scale spots of biotite and chlorite. Contains a 10 m blob of fine to very coarse-crystalline calcite–actinolite–wollastonite–garnet calcsilicate at W113.277987°, N45.792906° (T. 1 N., R. 14 W., sec 36, NE1/4, SE1/4). Thickness unknown.

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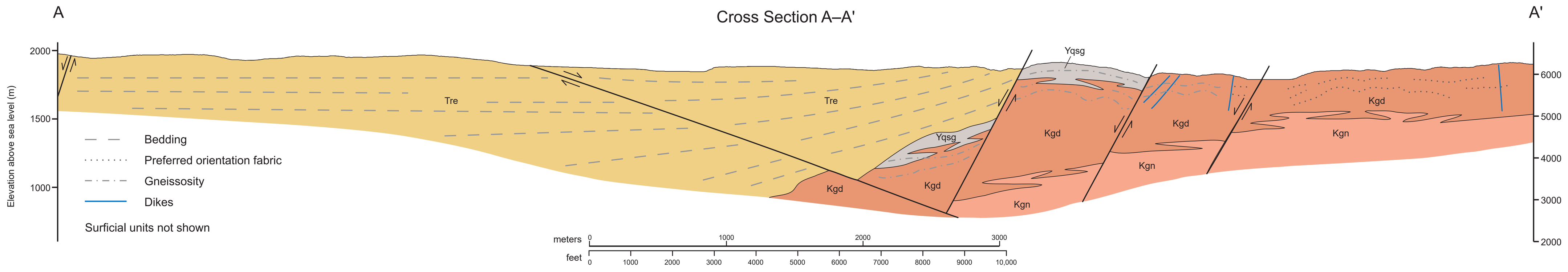
Figure 2. Coarse variant of Cretaceous quartzite, schist, and gneiss (Yqsgc). Note dismembered pelitic blob in lower right. Sunglass lens 5 cm across long dimension.

Figure 3. Cretaceous hornblende biotite granodiorite (Kgd) that is massive (a) and sub-gneissic (b). Field of view in (b) is 25 cm.

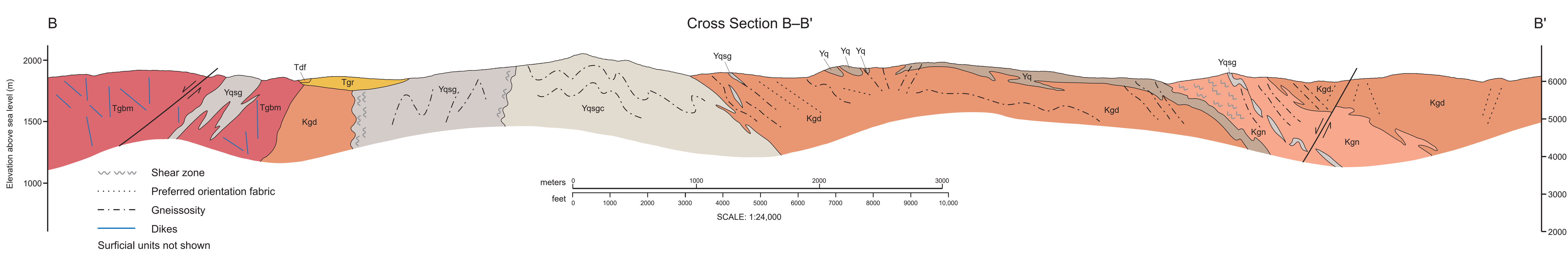
Figure 4. Rare exposure of clay-rich beds in Tre. Hammer for scale.

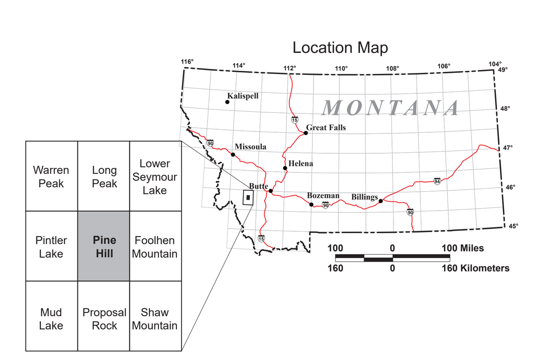
Figure 5. Tertiary gravel (Tgr) lag on the top of Chalk Bluff (a) and quartzite cobble with a typical tan weathering rind (b). Toe of shoe for scale.

Cross Section A–A'



Cross Section B–B'





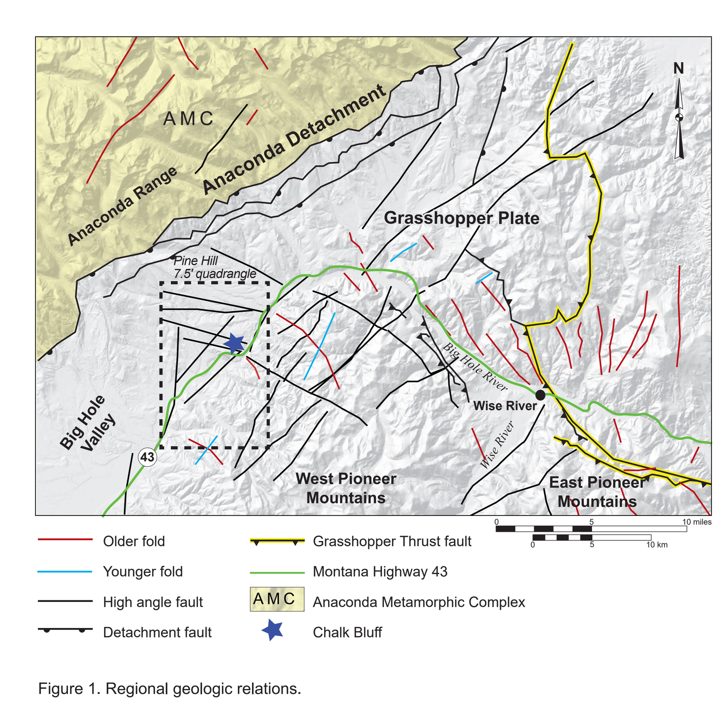


Figure 1. Regional geologic relations.

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

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Geologic Map 87

Geologic Map of the Pine Hill 7.5' Quadrangle Southwest Montana

Colleen G. Elliott

2022

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