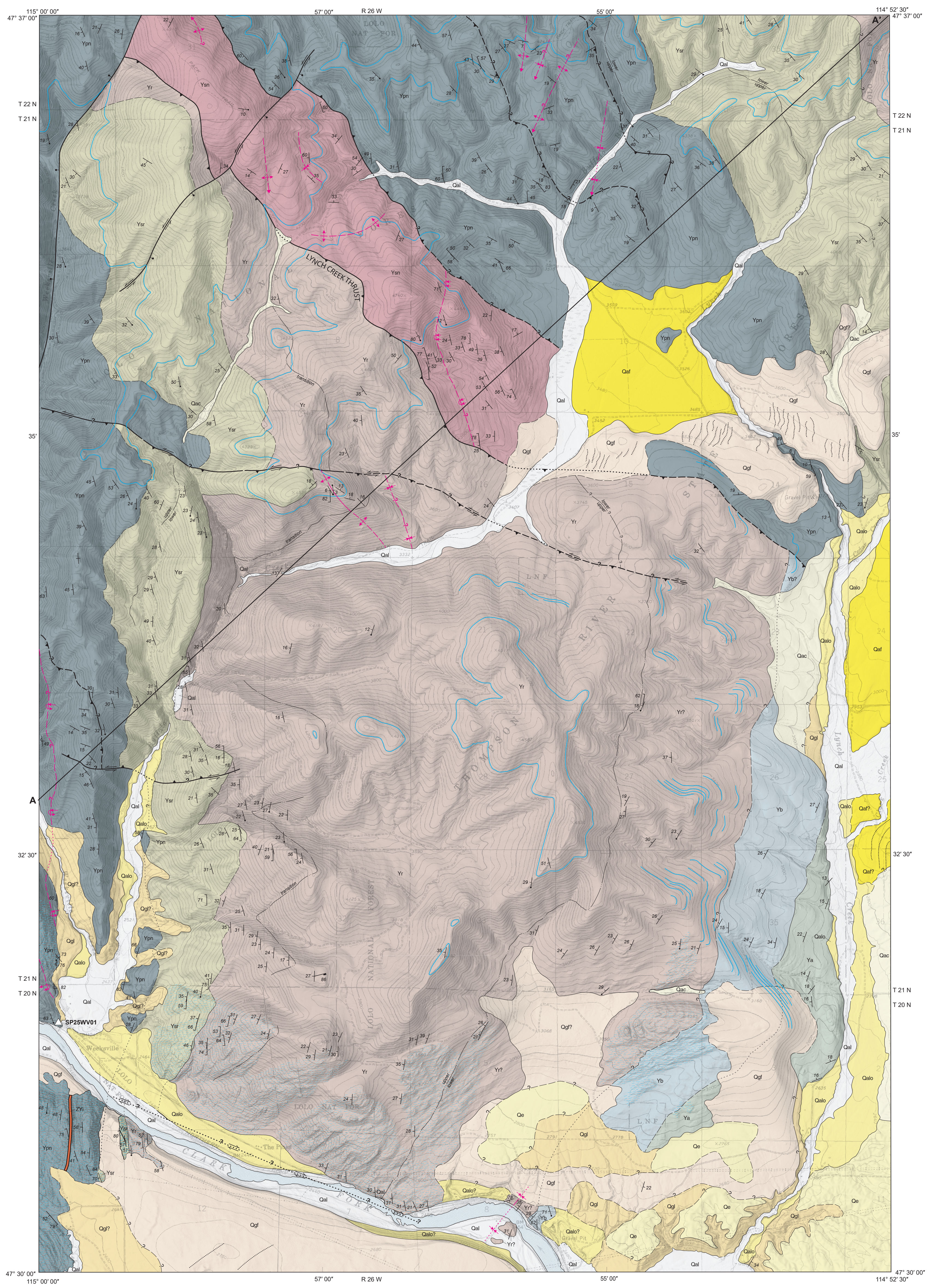
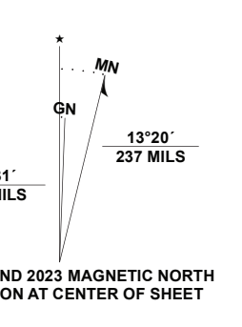
MONTANA BUREAU OF MINES AND GEOLOGY
A Department of Montana Technological University

MBMG Geologic Map 112; Plate 1 of 1
Geologic Map of the Weeksville 7.5′ Quadrangle, 2026



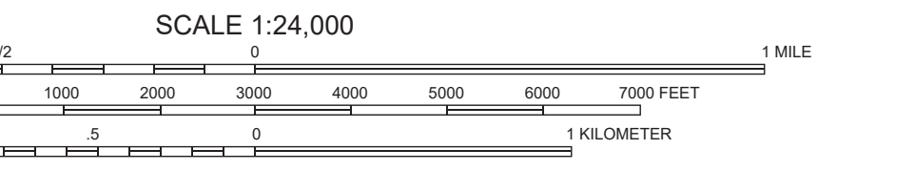
Base map produced by the United States Geological Survey
Weeksville 1:24,000-scale quadrange map
Control by: USGS and USC&GS
Compiled from aerial photographs taken 1963
Field checked: 1964
Projection: Polyconic
Grid:1000 meter Universal Transverse Mercator Zone 11
Vertical Datum: Mean sea level
Horizontal Datum: 1927 North American Datum

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



UTM GRID AND 2023 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

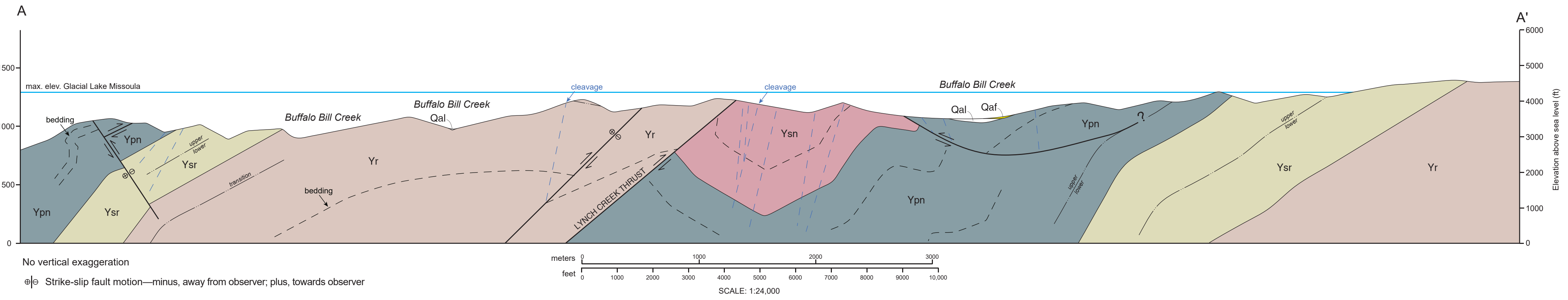
SCALE 1:24,000



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
https://mbmg.mtech.edu

Cross-Section A–A′

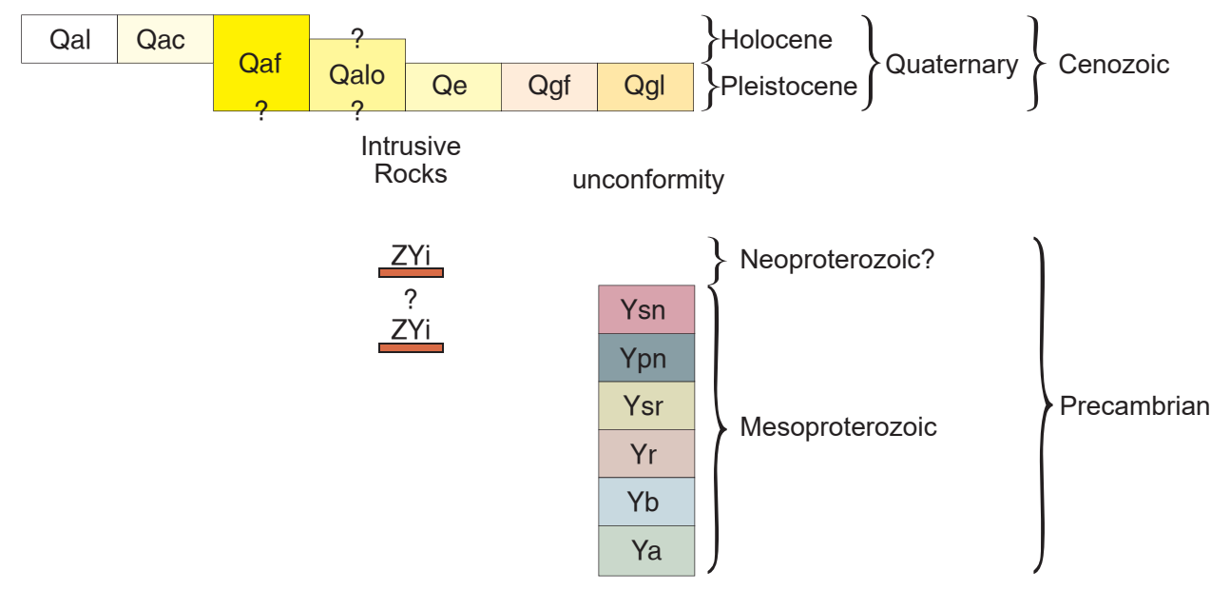


No vertical exaggeration

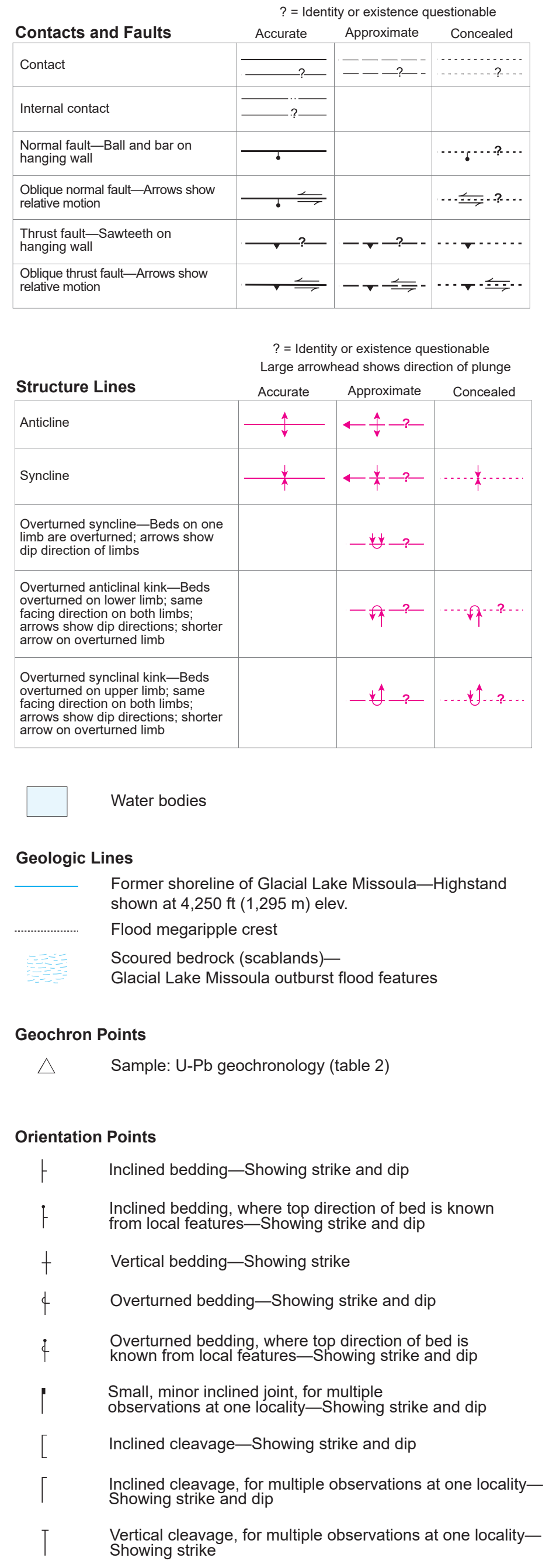
⊕|⊖ Strike-slip fault motion—minus, away from observer; plus, towards observer

Research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award G24AC00336-00.
GIS production: Stuart D. Parker, Patricia E. Gallagher, and Yiwen Li, MBMG. Map layout: Susan Smith, MBMG. Editing: Susan Barth, MBMG.

CORRELATION DIAGRAM



MAP SYMBOLS



? = Identity or existence questionable

Contacts and Faults — Accurate, Approximate, Concealed

- Contact
- Internal contact
- Normal fault—Ball and bar on hanging wall
- Oblique normal fault—Arrows show relative motion
- Thrust fault—Sawteeth on hanging wall
- Oblique thrust fault—Arrows show relative motion

? = Identity or existence questionable
Large arrowhead shows direction of plunge

Structure Lines — Accurate, Approximate, Concealed

- Anticline
- Syncline
- Overturned syncline—Beds on one limb are overturned; arrows show dip direction of limbs
- Overturned anticlinal kink—Beds overturned on lower limb; same facing direction on both limbs; arrows show dip directions; shorter arrow on overturned limb
- Overturned synclinal kink—Beds overturned on upper limb; same facing direction on both limbs; arrows show dip directions; shorter arrow on overturned limb

Water bodies

Geologic Lines

- Former shoreline of Glacial Lake Missoula—Highstand shown at 4,250 ft (1,295 m) elev.
- Flood megaripple crest
- Scoured bedrock (scablands)—Glacial Lake Missoula outburst flood features

Geochron Points

△ Sample: U-Pb geochronology (table 2)

Orientation Points

- Inclined bedding—Showing strike and dip
- Inclined bedding, where top direction of bed is known from local features—Showing strike and dip
- Vertical bedding—Showing strike
- Overturned bedding—Showing strike and dip
- Overturned bedding, where top direction of bed is known from local features—Showing strike and dip
- Small, minor inclined joint, for multiple observations at one locality—Showing strike and dip
- Inclined cleavage—Showing strike and dip
- Inclined cleavage, for multiple observations at one locality—Showing strike and dip
- Vertical cleavage, for multiple observations at one locality—Showing strike

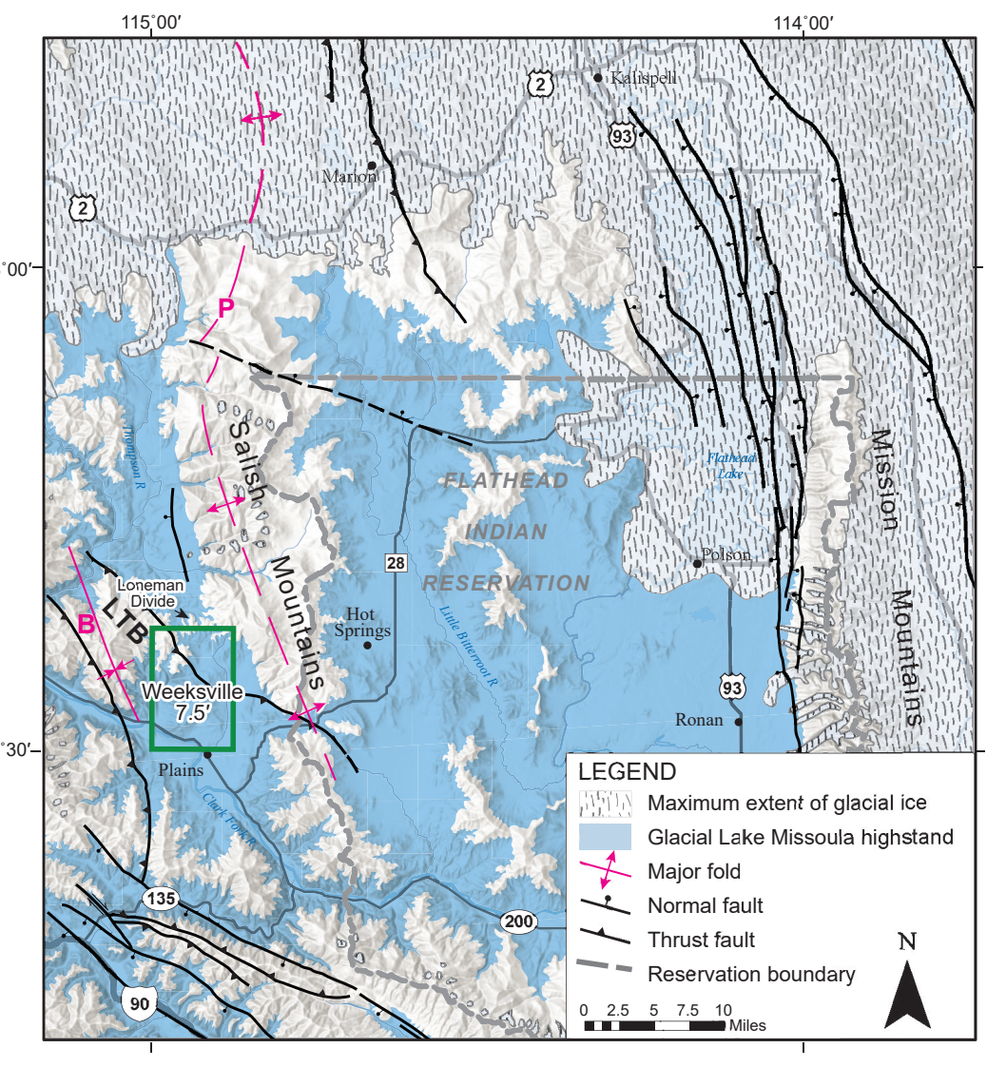
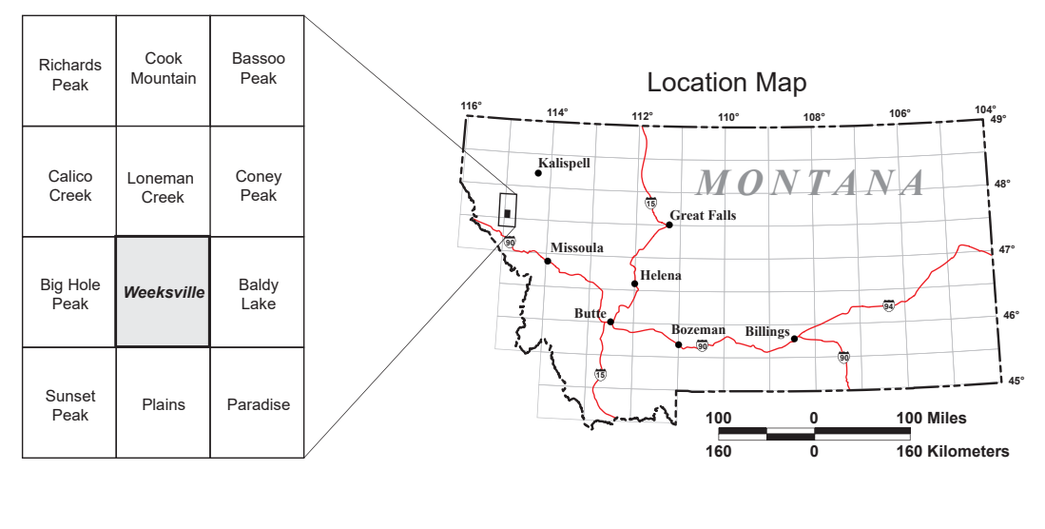


Figure 1. Overview map of the Weeksville 7.5′ quadrangle (green box) and surrounding area. Major faults shown. Maximum extent of glacial ice and highstand of Glacial Lake Missoula modified from Smith and others (2021). Abbreviations include: LTB, Libby Thrust Belt; P, Purcell Anticlinorium; B, Big Hole Peak Syncline.



INTRODUCTION

The Weeksville 7.5′ quadrangle is situated along the Clark Fork of the Columbia River (hereby referred to as the Clark Fork) within the Salish Mountains, about 12 mi (20 km) north of Plains, Montana (fig. 1). The quadrangle is unglaciated, located along the path of the catastrophic floods that drained Glacial Lake Missoula (Pardee, 1942). The quadrangle covers the forested, gentle mountains south of Loneman Divide and the northwestern part of the Plains Valley. Elevations near the divide reach about 5,140 ft (1,565 m). The broad, north–northwest-striking mountain belt is dissected by a complicated and irregular network of small creeks, all of which flow into the Clark Fork. Buffalo Bill Creek cuts diagonally across the mountains, from northeast to southwest. To the east, Lynch Creek drains into the Plains Valley. The Plains Valley (or basin) is dominated by recent alluvium as well as Pleistocene lake sediments and flood deposits of Glacial Lake Missoula (Pardee, 1942). The low point in the quadrangle occurs along the Clark Fork, near the historic settlement of Weeksville, at about 2,440 ft (745 m) elevation.

PREVIOUS MAPPING AND METHODS

Previous geologic mapping in the Weeksville 7.5′ quadrangle is limited. Pardee (1942) included reconnaissance mapping of surficial deposits around the Plains Valley in his study of flood deposits related to the draining of Glacial Lake Missoula. Geologic maps by Harrison and others (1986, 1:250,000 scale) and Sears (1991, unpublished, 1:100,000 scale) are the only publications that cover the study area. Mauk (1983) and Winston (2016) measured and described a stratigraphic section of the Revett and part of the Burke formation, just north of the Clark Fork.

Digital elevation models (DEMs) derived from 1-m (1/3 ft) resolution light detection and ranging (lidar) data of Sanders County were used to identify and map surficial deposits and geomorphic features. DEMs were also used to create topographic profiles and estimate unit thicknesses. The lidar data, DEM, and hillshades used in this study are available through the Montana Lidar Inventory (https://msl.mt.gov/geoinfo/nrcs_partnership/imagery_and_elevation). The Montana Soils map, derived from the SSURGO database and made available through the Montana State Library and ArcGIS, was used to map the extent of eolian and glacial lake deposits. Available well logs from the Ground Water Information Center (https://mbmggwic.mtech.edu/) were used to constrain the thicknesses of surficial deposits and interpret their relative age relations.

The rock sample collected for U-Pb geochronology was processed at the MBMG mineral separation laboratory. Zircon was isolated by standard density and magnetic separation techniques. Zircon separates were analyzed by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) by Daniel Brennan and Skyler Mavor, MBMG, at the University of California, Santa Barbara. All data are reported in Brennan and others (in prep.).

GEOLOGIC SUMMARY

Deposition of the Belt Supergroup

The bedrock exposed in the Weeksville 7.5′ quadrangle is dominated by a thick (>20,000 ft, 6 km), moderately tilted section of slightly metamorphosed siliciclastic and carbonate rocks in the middle part of the Belt Supergroup (Appekunny to the Snowslip Formation). The exposed section reveals portions of the Ravalli, Piegan, and Missoula Groups, which were deposited in an enormous playa lake basin (e.g., Winston, 2007, 2016). The observed sediment types in the map area (table 1, fig. 2) suggest that deposition of the Appekunny to the Snowslip Formation occurred near the center of the Belt Basin, after about 1,470 to 1,440 Ma (Constenius and others, in review; Sears and others, 1998). Subaqueous transport and deposition of silty mud by storm waves occurred during deposition of the Appekunny Formation (Parker and Winston, in review). Following progressive draw-down of the Belt Sea, the Burke and Revett Formations were deposited mostly by subareal sheetfloods (fig. 2) that entered the playa during an extensive dry period (e.g., Winston, 2016). Marker intervals of green argillite couplets lacking desiccation cracks, such as the interval below the lower internal contact in the Revett Formation, represent wetter episodes and a return of the Belt Sea (Mauk, 1983). With rising water levels, subaqueous conditions returned and persisted during deposition of the St. Regis Formation and Piegan Group (e.g., Hrabar, 1971; Grotzinger, 1981; Winston, 2007). This flooding was more gradual or episodic in the more central part of the basin (footwall of the Lynch Creek Thrust), where sediment types suggest episodic ponding and desiccation (fig. 2). Eventually, during contraction of the Belt Sea, evaporation exceeded fresh-water inflows and carbonate (mostly dolomite) cement overprinted the thin siliciclastic sediments of the lower Piegan Group (Winston, 2007). During relative highstands or expansions of the Belt Sea, storm events with sizable waves drove sandy bedforms across the basin (Winston, 2007). The Belt Sea ultimately contracted and eventually dried up, returning to episodic playa and shallow-water conditions during deposition of the Snowslip Formation (Lemoine, 1979).

Structural Geology

A northwest–southeast-striking thrust fault places the Ravalli Group over the upper Piegan and lower Missoula Groups, omitting about 10,000–14,000 ft (3–4.5 km) of section. This fault is within the southern part of the Libby Thrust Belt of Harrison and Cressman (1993), herein named the Lynch Creek Thrust [defined by the readily apparent thrust fault relationships just west of Lynch Creek (sec. 14, T. 21 N., R. 26 W.)]. Near the cross-section line, the Lynch Creek Thrust dips approximately 40° to the southwest. The footwall ramp of the thrust cuts the southwest-dipping limb of the Purcell Anticlinorium (fig. 3D; Harrison and Cressman, 1993). In the footwall, the Snowslip Formation is folded into a tight (~70° interlimb angle), overturned, east–northeast-verging syncline with axial planar cleavage (fig. 3C). Outcrop-scale folding and inferred detachments in the Piegan Group suggest bed-parallel slip, which is perhaps related to local backthrusting. The hanging wall of the Lynch Creek Thrust is broken by subparallel, oblique, left-lateral thrust faults. Hanging wall strata define an open kink fold that shares the eastern limb of the Big Hole Peak syncline (fig. 3B; e.g., Grotzinger, 1981). The shared limb of this syncline–anticline is more steeply dipping south of the Clark Fork, suggesting that a steep fault with an apparent right-lateral offset is concealed beneath the river. These observations suggest a top-to-the-east-northeast sense of slip on the Lynch Creek Thrust.

The Lynch Creek Thrust fault is offset by two unnamed, generally north–south- to northeast–southwest-striking faults. Apparent offsets are consistent with general east–west extension. These are the only two mapped faults in the quadrangle that clearly post-date the Cordilleran Orogeny and accommodated regional extension in the Cenozoic (e.g., Constenius, 1996; Schmeelk and others, 2017).

Pleistocene Geology

During the Pleistocene, the map area was flooded by Glacial Lake Missoula (e.g., Pardee, 1910, 1942). During its highstand, when the elevation of the lake level was around 4,250 ft (1,295 m; O’Connor and others, 2020), most of the map area was submerged (fig. 1). The lowest saddle on Loneman Divide was just barely overtopped, and the surrounding mountains were exposed as small islands. Density flows of turbid water flowed down slope into the Plains Basin, forming rhythmically bedded lake sediments (Pardee, 1942). Wave action formed pebbly shorelines around the Plains Valley, except in the more protected coves (Pardee, 1942). Following failures of the ice dam that impounded Glacial Lake Missoula, catastrophic floods drained the small catchments around the valley, with the main flood path following the Clark Fork, scouring bedrock and depositing extensive flood gravels (Pardee, 1942). The flat-topped gravel deposit near Lynch Creek was formed by flood waters that spilled over the elevated bench, or by a delta that prograded into the lake when the water level was at around 3,400 ft (1,035 m). A thinner set of rhythmically bedded lake sediments overlies flood deposits, demonstrating that the final drawdown of Glacial Lake Missoula was gradual (Pardee, 1942). Following the end of the last glaciation, before vegetation colonized the exposed lake bottom, aeolian sand dunes migrated across the valley. The modern Clark Fork and its tributaries have since incised sediments of the Plains Basin. Bedrock incision and an abrupt bend in Lynch Creek, as well as very low gradients and ponding along Buffalo Bill Creek, suggest that recent incision of the Plains Basin may have captured local streams that previously entered directly into the Clark Fork further downstream.

DESCRIPTION OF MAP UNITS

Qal **Alluvium (Holocene)**—Unconsolidated, moderately sorted deposits of stream-rounded gravel and sand. Deposited by modern streams. Channel deposits include rounded clasts, up to cobble- or small boulder-sized. Locally includes unconsolidated paludal deposits of silt, organic material, and minor clay deposited in marshes and fine-grained alluvial deposits of moderately sorted sand to clay deposited by streams. Unit is inset into older alluvium and colluvium along the Clark Fork and its tributaries. Thickness may be as much as 200 ft (60 m) near the Clark Fork.

Qac **Alluvium and colluvium (Holocene)**—Unconsolidated, poorly sorted to moderately sorted deposits of angular to subrounded pebbles to cobbles and finer sediment in a tan to pink, silty to sandy matrix. Deposited in small drainage bottoms and on gentle hillsides by sheetwash and hillslope processes from adjacent hillsides. Thickness may be as much as 25 ft (8 m) in drainages, based on topographic profiles, and as much as 120 ft (36 m) on hillslopes, based on available well logs.

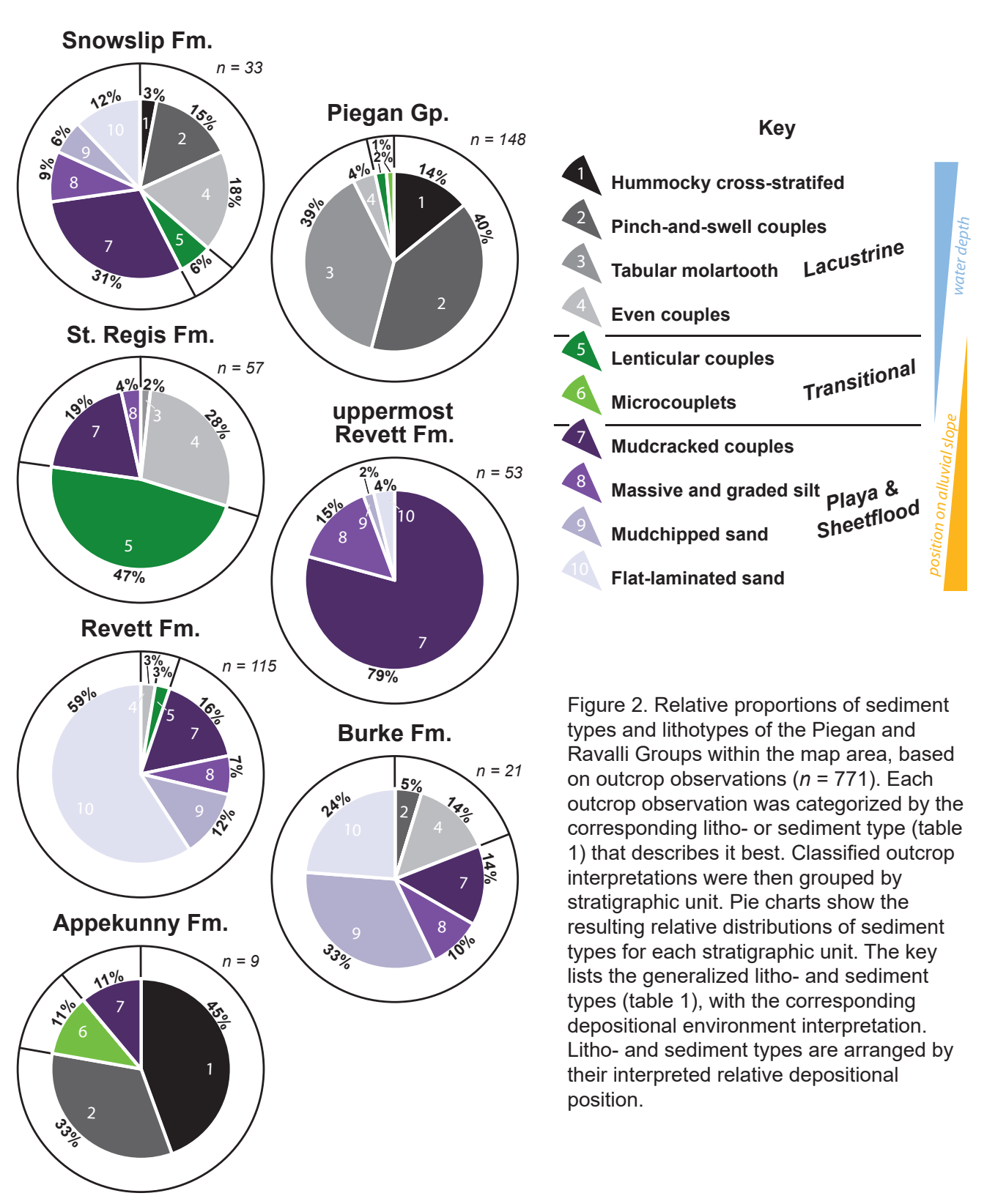


Figure 2. Relative proportions of sediment types and lithotypes of the Piegan and Ravalli Groups within the map area, based on outcrop observations (*n* = 771). Each outcrop observation was categorized by the corresponding litho- or sediment type (table 1) that describes it best. Classified outcrop interpretations were then grouped by stratigraphic unit. Pie charts show the resulting relative distributions of sediment types for each stratigraphic unit. The key lists the generalized litho- and sediment types (table 1), with the corresponding depositional environment interpretation. Litho- and sediment types are arranged by their interpreted relative depositional position.

Qaf **Alluvial fan deposit (Holocene to Pleistocene)**—Unconsolidated, moderately sorted deposits of subrounded to subangular pebble to boulder gravel. Matrix-supported, with open pores and some interstitial mud. Clasts are locally sourced, mostly from resistant quartzites and siltites. Deposits along the eastern edge of the map, sourced from Cedar, Hinchwood, and Clark Creeks, are as old as Pleistocene and rest on or are interbedded with Glacial Lake Missoula sediments. Fan deposits sourced from upper Lynch Creek overlie Pleistocene flood gravels and are likely Holocene in age. Thickness in well logs is less than 200 ft (60 m).

Qalo **Alluvium, older than Qal (Holocene to Pleistocene?)**—Unconsolidated, moderately sorted deposits of stream-rounded pebble to cobble gravel and sand. Channel deposits include rounded clasts, up to small boulders. Forms terraces above the Clark Fork and its tributaries. Deposited on flood-scoured bedrock and inset into Pleistocene and younger deposits, suggesting a Holocene age, except near the Plains Valley where it underlies Pleistocene flood gravels. Thickness is more than 80 ft (25 m) in available well logs and possibly up to 200 ft (60 m) near the Clark Fork.

Qe **Eolian deposit (Pleistocene)**— Unconsolidated, brownish tan to light pink, very well-sorted, subangular, very fine sublithic sand and uncommon sandy mud, representing wind-blown sand dune deposits. Easily identified based on the presence of sandy soils. Occurs in the southeastern corner of the map area. Rests unconformably on bedrock of the Belt Supergroup (Yr, Ya) and Glacial Lake Missoula sediments (Qgl) and flood gravel. (Qgf) Thickness in well logs is less than 22 ft (7 m) in map area.

Qgf **Glacial flood deposit (Pleistocene)**—Unconsolidated to loosely consolidated, moderately to poorly sorted, angular to subrounded, cobble to boulder gravel and moderately sorted, subangular to round pebble gravels with a sandy matrix. Commonly composed of a limited diversity of clast lithologies, suggesting a semi-local source from recycled alluvium and colluvium. Pebble gravels are common in low-energy backwaters and eddies, north of the Clark Fork and near Lynch Creek. Deposits above the bedrock canyon along Lynch Creek have a flat upper surface at about 3,500 ft (1,065 m) elevation and a steep face at the toe, representing either a flood expansion bar or an older delta deposit within Glacial Lake Missoula. Deposits south of the Clark Fork form a very large, hummocky bar complex where well-sorted, medium-grained sand overlies flood gravel. Flood bars rest unconformably on scoured bedrock of the Belt Supergroup and on older alluvium and Glacial Lake Missoula sediments within the Plains Valley. Apparent thickness is up to about 200 ft (60 m) near Lynch Creek, 100 ft (30 m) north of the Clark Fork, and 50 ft (15 m) south of the Clark Fork.

Qgl **Glacial lake deposit (Pleistocene)**—Beige to pinkish tan, even parallel, laterally continuous graded silt to clay layers and interbedded pebble gravel with a sandy matrix. Graded layers range from couplet (<¼ in, <½ cm) to couple (>¼ in, >½ cm) scale. Rarely exposed, but easily identified based on the presence of clay-rich soils. Consists of a main package that apparently rests on bedrock of the Belt Supergroup, and a very thin upper package that overlies glacial flood deposits. Thickness is typically less than about 60 ft (18 m), but may exceed about 90 ft (25 m) thick towards the Plains Valley bottom, according to well logs. Upper package is less than about 5 ft (1½ m) thick.

ZYi **Gabbro sill (Mesoproterozoic? to Neoproterozoic?)**—Black, brown to rusty weathering gabbro sill. Very fine-grained with no visible crystals. Poorly exposed, only within Piegan Group in southwestern corner of the map area. Age may be either Mesoproterozoic or Neoproterozoic, like sills dated in the nearby Prichard Formation (Sears and others, 1998; Parker, in prep.). Thickness is only about 15 ft (5 m).

BELT SUPERGROUP

The Belt Supergroup is a very thick (50,000 ft, 15 km; Lonn and others, 2020) succession of low-grade metasedimentary rocks with well-preserved primary sedimentary structures. Formations have gradational contacts and are defined by their sedimentary rock protoliths. Because depositional features are preserved, the descriptions in this map refer to the inferred primary grain sizes (sand, silt, clay) of the sedimentary rock protolith rather than the general metamorphic rock types (quartzite, siltite, argillite). Graded layers less than about 1 in (3 cm) thick are termed couplets; about 1–4 in (3–10 cm) thick are termed couples. Layers greater than 4 in (10 cm) thick are termed beds; greater than about 1 ft (30 cm) are termed thick beds.

Common associations of primary grain sizes, layer thicknesses, bed geometry (bedforms), and sedimentary structures define sediment types (e.g., Winston and Link, 1993; Winston and Smith, 2016). Similarly, when diagenetic features obscure primary features, lithotypes are used. Unit descriptions refer to the associations of key litho- and sediment types that best define formations. See table 1 for detailed descriptions of the litho- and sediment types of the Piegan Group. See Parker (2025) for annotated photos of sediment types of the Ravalli Group, exposed in the neighboring Murr Creek 7.5′ quadrangle.

Ysn **Snowslip Formation of the Missoula Group (Mesoproterozoic)**—Interbedded dark to light green siltite to argillite couplets, red to purple fine-grained quartzite to siltite couples, and distinctive rosy red siltite to argillite couplets. Beds of fine-grained feldspathic quartzite up to a few decimeters thick also occur. Desiccation cracks and mud rip-up clasts are abundant throughout (mudcracked couple sediment type, table 1, fig. 2), and distinguish Snowslip Formation from the underlying Piegan Group. Bedding surfaces commonly contain bumps that resemble trace fossils, but that are probably features developed from microbial mats (Horodyski, 1982). The lowest 500 ft (150 m) are characterized by dolomitic and non-dolomitic dark to light green siltite to argillite microlaminae (microcouplet sediment type). In the map area, the lower contact is a fault and a complete section is not exposed, but thickness is at least 2,100 ft (640 m).

Ypn **Piegan Group (Mesoproterozoic)**—Banded, wavy, continuous to discontinuous dark gray to white, tan-weathering fine-grained quartzite with sharp, dark argillite caps, interlayered with dark gray, tan to orange-brown-weathering dolomitic intervals with pervasive molartooth structure (pinch-and-swell couple sediment type and tabular molartooth lithotype, table 1, fig. 2). Thicker sand beds, around 4–6 in thick (10–20 cm), commonly have internal flat to hummocky laminations (hummocky cross-stratified sediment type, table 1, fig. 2). Layering ranges from couplet to bed scale, with common scoured bases, sand-filled subaqueous shrinkage cracks (“crinkle cracks” of Winston and Smith, 2016), soft-sediment deformation, ripple cross-lamination, and hummocky cross-stratification throughout. Dolomite and calcite cement commonly overprints and obscures primary sedimentary structures, often forming massive outcrops about 3 ft (1 m) thick, with pervasive molartooth structure (tabular molartooth lithotype, table 1, fig. 2). Gray-weathering, recessive limestone nodules and lobate layers in dark argillite are uncommon (fig. 4). Hummocky cross-stratified sand and tabular molartooth (table 1, fig. 2) are generally more common in the poorly exposed lower part. Internal contact is placed below the lowest interval of pinch-and-swell couples, which are widespread throughout the upper part of the unit. Lower contact with the St. Regis Formation is gradational, placed just below the stratigraphically lowest float of the tabular molartooth lithotype. Upper contact is not exposed in the map area. Unit is correlative with the cyclic and sandy members of the Wallace Formation of Grotzinger (1981) and the Helena and Wallace Formations of Winston (2007), which cannot be differentiated in the map area. Lower part appears to be mostly correlative with the lower Helena member of the Helena Formation of Winston (2007). Apparent thickness of about 7,000 ft (2,130 m) in the footwall of the Lynch Creek Thrust.

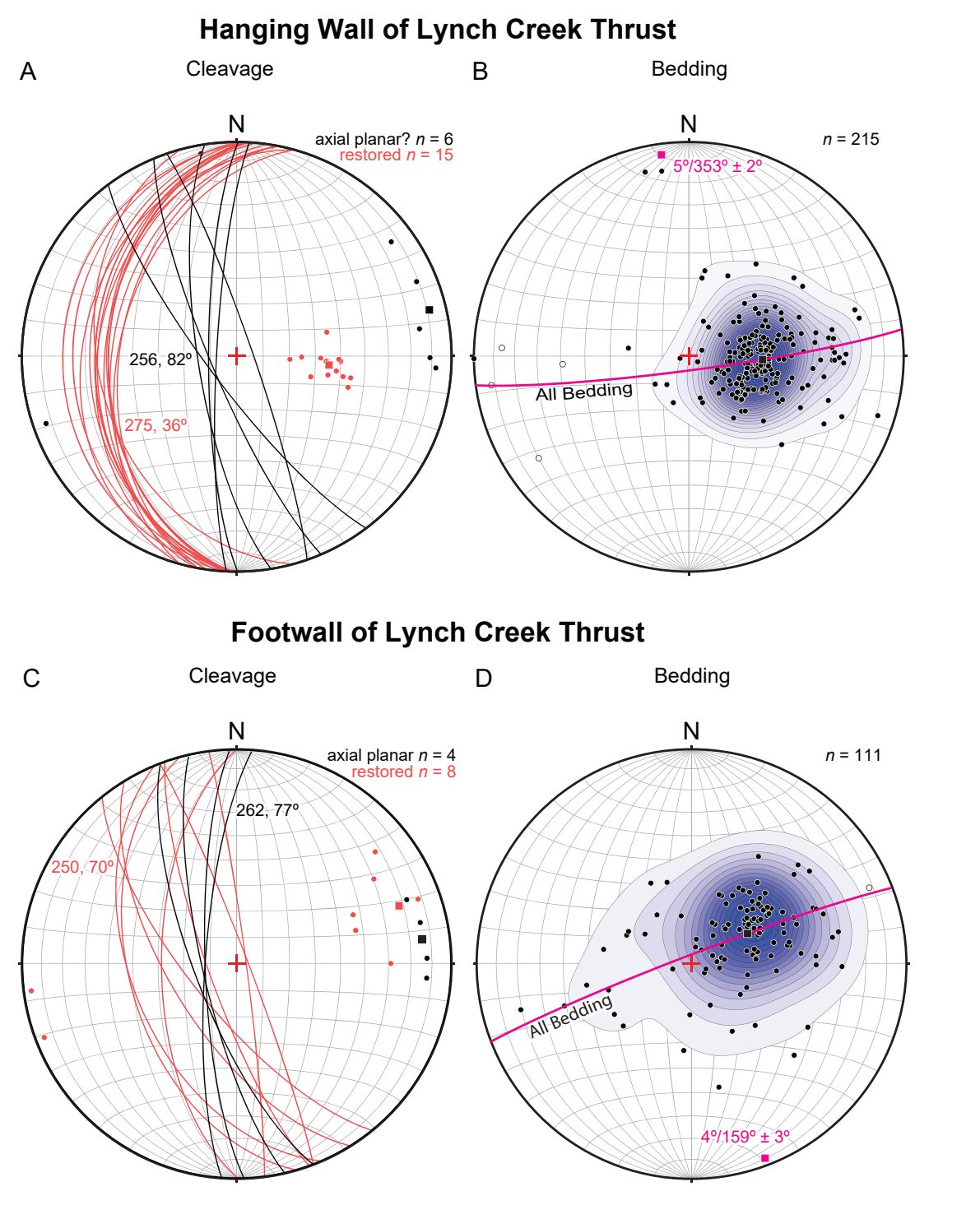


Figure 3. Lower hemisphere stereographic projections showing measured cleavage and bedding planes within the map area. Shading denotes Kamb contouring with 2σ-uncertainty envelopes. (A, C) Cleavage planes, poles to planes, and mean pole. Axial planar cleavage planes plotted as measured. Restored cleavage planes plotted after rotating associated bedding to horizontal. Mean plane labeled. (B, D) Poles to bedding with calculated best fit girdle, mean pole, and fold hinge and uncertainty labeled. Hollow datapoints show poles to overturned bedding.

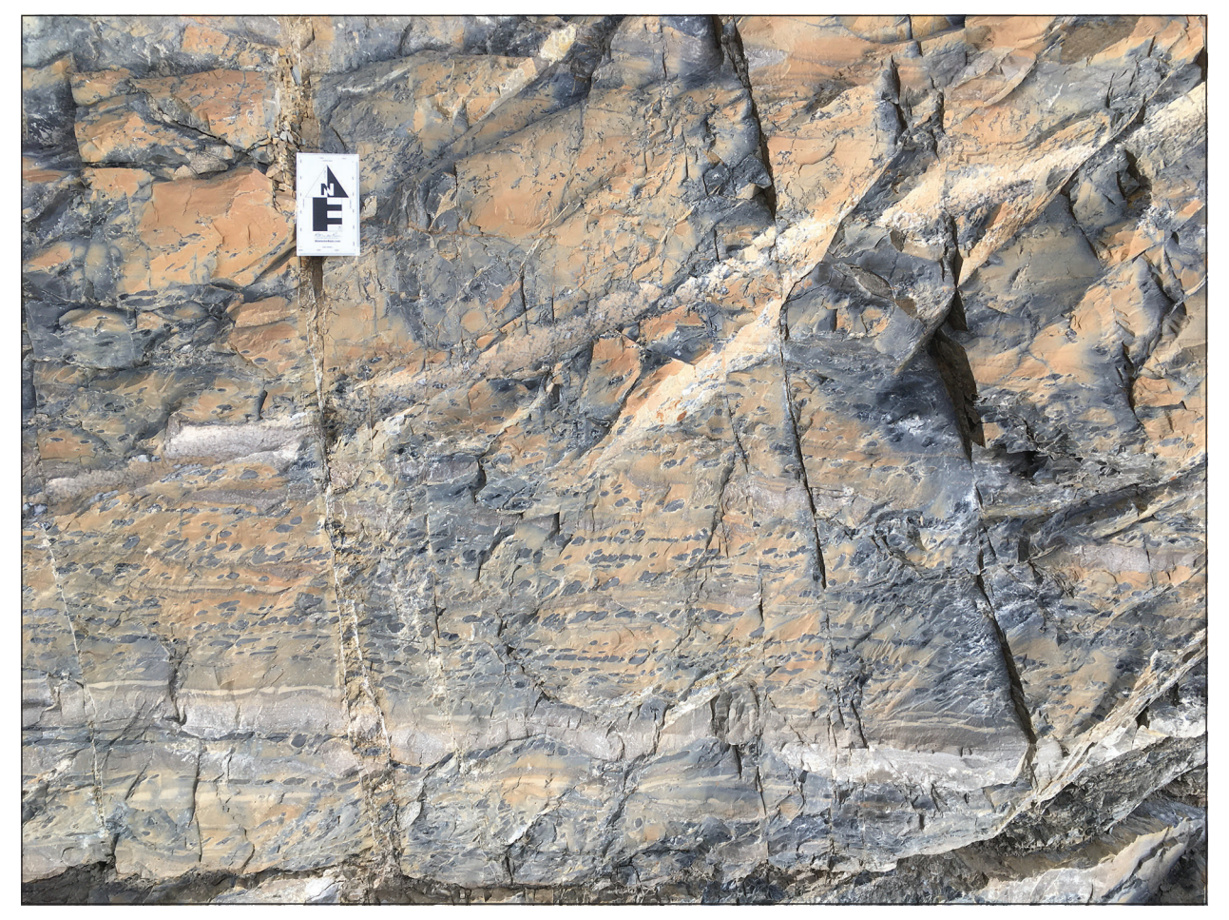


Figure 4. Outcrop photo of the tabular molartooth lithotype, within the Piegan Group. Lower part shows gray nodular limestone within dolomitic pinch-and-swell couples. Upper part shows pervasive, calcite-filled molartooth structure within dolostone where sedimentary structures are difficult to see.

Ysr **St. Regis Formation of the Ravalli Group (Mesoproterozoic)**—Gray to green, tan-weathering, very fine-grained quartzite or siltite to argillite couples and couplets, and purple, mudcracked, even, very fine-grained quartzite or siltite to argillite couples and couplets (lenticular, even, and mudcracked couplet sediment types, table 1, fig. 2). Lenticular and even couples (table 1, fig. 2) range from about ¼–4 in (½–10 cm) thick. Lenticular couples range from indistinct, wavy, and continuous layers with subtle grading to distinct rippled layers of white, well-sorted, fine-grained quartz sand with rare dolomitic cement. Rippled sand layers are recessive and tan-brown-weathering, ranging from discontinuous layers of isolated crests to continuous beds of climbing symmetric ripple sets. Mudcracked couples (table 1, fig. 2) range from about ¼ to1½ in (½ to 4 cm) thick, with common polygonal desiccation cracks and mud chips with upturned cusps. Isolated, aligned to intersecting spindle-shaped, sand-filled subaqueous shrinkage cracks (“crinkle cracks” of Winston and Smith, 2016) are common throughout. Lower part consists mostly of interbedded purple and green to gray mudcracked, even, and lenticular couples and couplets (type 1 cycle of Winston and Lyons, 1997). Upper part consists mostly of green to gray, tan-weathering lenticular couples and even continuous couples and couplets, sometimes with partly dolomitic cement and recessive weathering voids (type 2 cycle of Winston and Lyons, 1997). Internal contact is placed below the stratigraphically lowest molartooth structure. Upper contact is very gradational, being sharper in the hanging wall of the Lynch Creek Thrust, and is placed just below the lowest occurrence of either the molartooth lithotype (table 1, fig. 2) or red-weathering, dolomitic, fine- to medium-grained quartzite (hummocky sand sediment type, table 1, fig. 2). In the hanging wall of the Lynch Creek Thrust, the upper contact is placed below the lowest pinch-and-swell couples (table 1, fig. 2). Unit is apparently correlative with the upper St. Regis of Hrabar (1971). The lower part is partly correlative to the St. Regis Formation of Mauk (1983), Grotzinger (1981), and Winston (2007, 2016); upper part is correlative to the green member of the Wallace Formation of Grotzinger (1981), and the Empire Formation of Winston (2007). Unit is about 3,000 ft (920 m) thick in the footwall of the Lynch Creek Thrust, and about 1,500 ft (460 m) thick in the hanging wall.

Yr **Revett Formation of the Ravalli Group (Mesoproterozoic)**—Gray to blue-gray to white, tan-weathering, thick-bedded, very fine-grained quartzite with abundant asymmetric climbing ripples and uncommon crossbedding (flat-laminated sand sediment type, table 1, fig. 2), interbedded with thin to thick, tabular siltites and very fine-grained quartzites with thin mud drapes (mudchipped sand and graded silt sediment types, table 1, fig. 2) and greenish to purplish argillite composed of very fine sand or silt to clay couples with abundant desiccation cracks (mudcracked couple sediment type). Quartzite is generally defined by well cemented, very-fine-grained and well sorted quartz sand; commonly with flat laminations near the base and climbing ripple sets (asymmetric, straight crested and lunate) near the top of beds. Diagenetic banding, thin mud drapes, and load structures are common. Quartzite is rarely cross-bedded. Quartzite and siltite beds are tabular, ranging from about 4 in (10 cm) to 6 ft (2 m) thick. In the map area, quartzites of the Revett Formation are difficult to differentiate from those of the underlying Burke Formation. In general, the predominance of thick-bedded quartzites belonging to the flat-laminated sand sediment type distinguishes the Revett from the Burke (table 1, fig. 2). Lower internal contact placed above resistant marker interval of green argillite (mudcracked, even, and lenticular couple sediment types, table 1, fig. 2). Upper internal contact placed above highest thick (>3 ft; >1 m), fine-grained quartzite bed and below the lowest interval of distinct maroon and purple mudcracked couples. This uppermost internal part of the Revett also contains common interbeds of tabular graded silt and rare interbeds of flat-laminated and mudchipped sand (table 1, fig. 2). Upper contact is gradational, placed below the lowest lenticular couple interval, typically within green argillite (table 1, fig. 2). The lower Revett shown on this map was included in the upper Burke by Mauk (1983) and Winston (2016). The uppermost Revett was included in the St. Regis Formation by Mauk (1983), Grotzinger (1981), and Winston (2007, 2016), but is herein included in the Revett based on the associated sediment types (fig. 2). Lower part is about 2,500 ft (760 m) thick. Upper part is about 5,000 ft (1,525 m) thick.

Yb **Burke Formation of the Ravalli Group (Mesoproterozoic)**—Green-gray to purple-gray, tan- to orange-weathering, thin-bedded, crudely tabular, very fine-grained quartzite with uncommon desiccation cracks and mudchips (mudchipped sand subtype, table 1, fig. 2) and argillite with common desiccation cracks in thin mud drapes (mudcracked couplet and graded silt sediment types, table 1, fig. 2). Quartzite is generally very fine-grained and well-sorted, with uncommon disseminated magnetite grains, rare sericite, and very thin mud drapes that give the rock a flaggy appearance. Common interbeds of thick-bedded quartzite (flat-laminated sand sediment type, table 1, fig. 2) are present throughout. In the map area, quartzites of the Burke Formation are difficult to differentiate from those of the overlying Revett Formation. In general, near-equal proportions of mudchipped sand, flat-laminated sand, and mudcracked couples distinguish the Burke from the Revett (fig. 2). Unit is mostly recessive and poorly exposed. Gradational upper contact is tentatively placed below the lowest interval of mostly thick-bedded quartzites of the flat-laminated sand sediment type. The Burke Formation on this map is correlative with, but more stratigraphically restricted than, the upper Burke of Mauk (1983) and Cressman (1985). Apparent thickness is about 1,250 ft (380 m).

Ya **Appekunny Formation (Mesoproterozoic)**—Dark green-gray to dark gray, light tan- to rusty-weathering, wavy, discontinuous laminated siltite to argillite (pinch-and-swell couple sediment type, table 1, fig. 2) and massive, very fine-grained quartzite to siltite beds with rare hummocky cross-stratification (hummocky cross-stratified sediment type, table 1, fig. 1). Rarely exposed, only in the southeastern corner of the map, above Lynch Creek. Isolated, aligned to intersecting spindle shaped, sand-filled subaqueous shrinkage cracks (“crinkle cracks” of Winston and Smith, 2016) are common throughout. Disseminated pyrite is uncommon. Rare microcouplets and mudcracked couplets in lower part suggest correlation with the marker interval in the middle of the Appekunny Formation, which may easily be mistaken for the Burke Formation (Parker and Winston, in review). Gradational upper contact, placed above highest pinch-and-swell couple, below lowest thick-bedded quartzite belonging to the flat-laminated sand sediment type. Unit is correlative to the lower Burke Formation of Mauk (1983) and Cressman (1985), the Transition member of the Prichard Formation of Cressman (1989), and the upper Appekunny Formation of Parker and Winston (in review). Lower contact is not exposed. At about 875 ft (265 m) thick in map area.

Table 1. Descriptions and interpreted depositional environment of litho- and sediment types referred to in the text. See Parker (2025), Winston (2007, 2016), and Winston and Link (1993) for more detailed descriptions of these general sediment types.

Sediment Type	Description	Interpretation
Hummocky cross-stratified	Tabular bedded coarse silt to medium sand with internal flat laminae and low-angle hummocky cross laminae. Low-relief, convex up hummocks with rare low-angle truncations, overlying flat laminae with sharp bases. Defines laterally continuous, tabular beds, typically ranging from about 4–16 in (10–40 cm) thick. Commonly interbedded with pinch-and-swell couples.	Sand bed load was transported and deposited by storm waves along the lake bottom. Suspended load has been winnowed away by constant wave action and currents.
Pinch-and-swell couples	Wavy, discontinuous layers and lenses of fine sand, sharply overlain by clay. Layers are couplet, couple, and bed scale, with sharp contacts and abrupt grading. Bases commonly have irregular scour and sand-filled crinkle cracks (Winston and Smith, 2016) cutting down into the underlying mud. Sand is typically gray with a slight blue or purple hue. Mud is typically dark black, and is uncommonly dolomitic. Hummocks are common in the thicker sand lenses.	Sand bed load was transported and deposited on a scoured and/or loaded muddy perennial lake bottom by storm waves. Mud settled out of suspension after or during the waning storm, in a perennial lake.
Tabular molartooth	Beds and thick beds, about 20–80 in (½–2 m) thick, of internally massive, tan- to orange-weathering dolostone and/or gray limestone with pervasive molartooth structure (fig. 4). Includes banded dolostone to limestone couples and nodules of light gray limestone in tan to orange dolostone, with sparse molartooth structure. Primary sedimentary structures are obscured, often beyond recognition. Recessive, often found as blocky float.	Diagenetic overprint, where dolomitic or calcitic cement precipitated in saturated, shallowly buried mud beneath a contracting perennial lake. Molartooth structure likely formed very early, just beneath the surface, as biogenic gas escaped wet mud during compaction (Furniss and others, 1998). Calcite cement later replaced the fill of the molartooth structure.
Even couples	Even to wavy, continuous, graded very fine sand/silt to clay couples and couplets with sharp, planar contacts. Wavy couples and couplets have parallel lower and upper contacts. Commonly purple or green and tan weathering.	Mud settled out from turbid water, below wave base or in still, protected water, after or during storms, in a perennial lake. Wavy layers were deformed during compaction of the wet sediment.
Lenticular couples	Fine sand/silt lenses, with sharp planar bases and ripple cross-laminae, capped by clay. Couple to couplet scale, with common crinkle cracks. Commonly green, tan weathering. Sandy, symmetrical ripple crests are often recessive weathering.	Sand bed load was transported and deposited on a muddy perennial lake bottom (or flooded playa) by gentle storm or fair weather waves. Mud settled out from turbid water after storms or times of increased wave action.
Microcouplets	Even, continuous silt to clay microcouplets and couplets, less than about ¼ in (½ cm) thick. Sometimes layers are continuous but contorted. Desiccation cracks uncommon. Usually black, light purple, or green, sometimes tan weathering. Recessive.	Mud settled out from slightly turbid water. Deposited either below wave base or in still, protected water. May have been deposited along a perennial lake bottom or where a distal sheetflood met a ponded playa.
Mudcracked couples	Even to wavy, continuous very fine sand/silt to clay couples and couplets with common desiccation cracks, asymmetric ripples, and mud chips. Commonly purple or green.	Coarse bed load was transported and deposited during a sheetflood. Mud settled out from turbid water during the waning flood or just after. Mud subsequently dried out and cracked. Deposited in a playa.
Massive and graded silt	Tabular, very fine sand/silt beds and couples, about 2–8 in (5–20 cm) thick, with sharp bases, massive to flat-laminated interiors, uncommon graded muddy silt tops, and rare, very thin, mm-scale (<1/8 in) mud/clay drapes with desiccation or crinkle cracks and common load structures. Often drab gray color, with slight purple, blue, or green hue in muddy intervals.	Coarse bed load was transported and deposited during a sheetflood. Trace amounts of mud settled out from turbid water as the flood waned. Most mud bypassed deposition. Mud subsequently dried out and cracked. Deposited low on a gently sloping alluvial apron.
Mudchipped sand	Crudely bedded to massive, fine/very fine sand beds, about 8–60 in (20 cm–1½ m) thick, with sharp bases and internal laminae, defined by slight grading with interstitial mud. Uncommon cross-laminae, asymmetric ripples, and mud chips. Rare, very thin mud drapes with desiccation cracks. Often has slight purple, blue, or green hue, indicating interstitial mud.	Coarse bed load was transported and deposited during a decelerating and shallowing sheetflood. Trace amounts of mud were deposited with the bedload, from the very turbid flood waters. Mud settled out from turbid water during the waning flood or just after. Mud subsequently dried out and cracked. Deposited on a gently sloping alluvial apron.
Flat-laminated sand	Tabular bedded fine/very fine sand beds with sharp bases, massive to flat-laminated lower parts, uncommon climbing-ripple upper parts, and rare mud drapes with desiccation cracks. Often white, tan, or drab gray color, with slight purple or blue hue in muddy intervals.	Coarse bed load was transported and deposited during a decelerating and shallowing sheetflood. Trace amounts of mud settled out from turbid water as the flood passed. Most mud bypassed deposition. Mud subsequently dried out and cracked. Deposited on a gently sloping alluvial apron.

Table 2. U-Pb zircon geochronology.

Sample	Sediment Type	Unit	Latitude (°N)	Longitude (°W)	# of Spot Analyses[a]	Maximum Depositional Age (Ma)	2σ	MSWD
SP25WV01	Pinch-and-swell couples	Ypn	47.5250	-114.9978	12/120	1472	12	1.1

Note. See Brennan and others (in prep.) for available data. Zircon separates were prepared at MBMG and analyzed by LA-ICP-MS at the University of California, Santa Barbara. Latitudes and longitudes are in the 1984 World Geodetic Survey (WGS84) datum.
[a] Numerator denotes the number of spot analyses used to calculate the weighted mean reported as the maximum depositional age; denominator denotes the total number of analyses in the sample. All analyses have a discordance of <10%.

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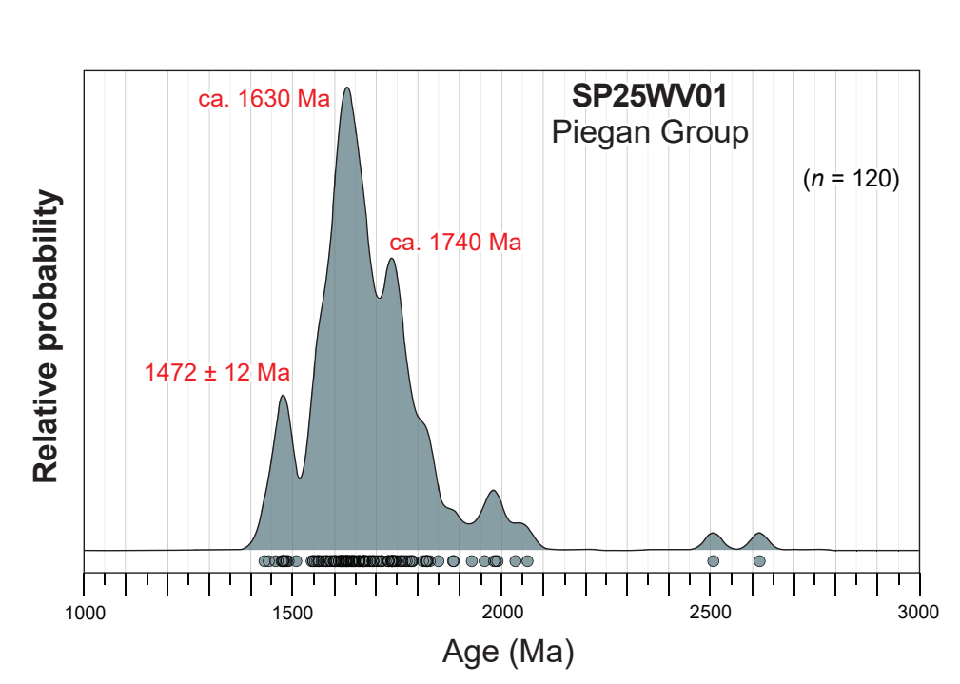

Figure 5. Kernel density estimate (KDE) plots of ^{207}Pb/^{206}Pb zircon ages with <10% discordance. Bandwidths of 20 m.y. and bin widths of 50 m.y. were used. Circles show individual age analyses. See table 2 for more information regarding maximum depositional ages. Data reported in Brennan and others (in prep.).

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Geologic Map 112

Geologic Map of the Weeksville 7.5′ Quadrangle, Sanders County, Montana

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