UTAH GEOLOGICAL SURVEY
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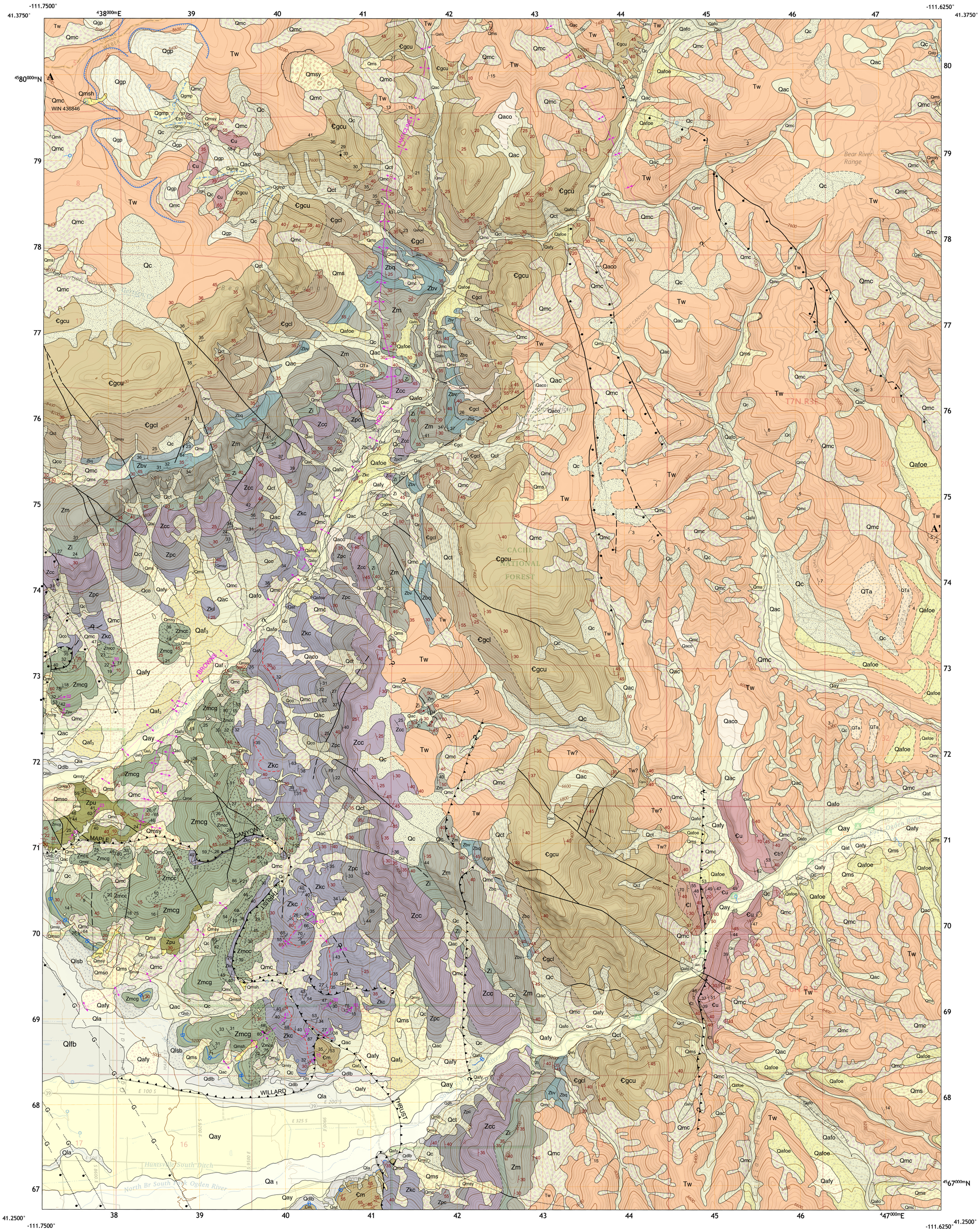

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10°57′
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2023

SCALE 1:24,000
1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET

Base from USGS US Topo Browns Hole 7.5′ Quadrangle (2023)
Projection: UTM Zone 12
Datum: NAD 1983

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UTAH
MAP LOCATION

INTERIM GEOLOGIC MAP OF THE BROWNS HOLE QUADRANGLE, WEBER AND CACHE COUNTIES, UTAH

by
Zachary W. Anderson[1], Gregory N. McDonald[1], Elizabeth A. Balgord[2], and W. Adolph Yonkee[2]

2023

[1] Utah Geological Survey, Salt Lake City, Utah
[2] Department of Earth and Environmental Sciences, Weber State University, Ogden, Utah

1	2	3
4	·	5
6	7	8

1.James Peak
2.Sharp Mountain
3.Monte Cristo Peak
4.Huntsville
5.Causey Dam
6.Snow Basin
7.Durst Mountain
8.Bybee Knoll

ADJOINING 7.5′ QUADRANGLE NAMES

UTAH GEOLOGICAL SURVEY
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LIST OF MAP UNITS

QUATERNARY-PLIOCENE (TERTIARY) DEPOSITS

- Qa_1 Youngest stream alluvium and floodplain deposits
- Qay Younger stream alluvium and floodplain deposits
- Qat Stream terrace deposits
- QTa High-level alluvial deposits
- Qaf_1 Youngest alluvial-fan deposits
- Qafy Younger alluvial-fan deposits
- Qaf_2 Level-3 alluvial-fan deposits related to transgressive phase of Lake Bonneville
- Qafo Older alluvial-fan deposits
- Qafoe Eroded older alluvial-fan deposits
- Qc Colluvial deposits
- Qco Older colluvial deposits
- Qgp Glacial deposits, undivided, Pinedale age
- Qgmp Glacial moraine till, Pinedale age
- Qlfb Lacustrine fine-grained deposits related to transgressive phase of Lake Bonneville
- Qlsb Lacustrine sand and gravel related to transgressive phase of Lake Bonneville
- Qdlb Deltaic and lacustrine deposits related to transgresssive phase of Lake Bonneville
- Qmsh Landslide deposits, historical movement
- Qmsy Younger landslide deposits
- Qms Landslide deposits
- Qmso Older landslide deposits
- Qac Undivided alluvial and colluvial deposits
- Qaco Undivided older alluvial and colluvial deposits
- Qct Undivided colluvium and talus deposits
- Qla Undivided lacustrine and alluvial deposits
- Qmc Undivided mass-movement and colluvial deposits

PALEOGENE (TERTIARY) ROCKS

- Tw Wasatch Formation

HANGING WALL ROCKS OF WILLARD THRUST SHEET

ORDOVICIAN AND CAMBRIAN ROCKS

- Ogc Garden City Formation (cross section only)
- €sc St. Charles Formation (cross section only)
- €n Nounan Formation (cross section only)
- €bo Bloomington Formation, undivided (cross section only)
- €b? Blacksmith Formation
- €u Ute Formation
- €l Langston Formation
- €gcu Upper member of Geertsen Canyon Quartzite of Brigham Group
- €gcl Lower member of Geertsen Canyon Quartzite of Brigham Group

NEOPROTEROZOIC ROCKS

- Zbq Quartzite member of Browns Hole Formation of Brigham Group
- Zbv Volcanic member of Browns Hole Formation of Brigham Group
- Zm Mutual Formation of Brigham Group
- Zi Inkom Formation of Brigham Group
- Zcc Caddy Canyon Quartzite of Brigham Group
- Zpc Papoose Creek Formation
- Zkc Kelley Canyon Formation
- Zmcc Conglomerate member of Maple Canyon Formation
- Zmcg Green arkose member of Maple Canyon Formation
- Zpu Upper member of Perry Canyon Formation

FOOTWALL ROCKS OF WILLARD THRUST SHEET

CAMBRIAN ROCKS

- €bn Bloomington and Nounan Formations, undivided (cross section only)
- €m Maxfield Limestone
- €o Ophir Formation (cross section only)

Thrust fault

JURASSIC AND TRIASSIC ROCKS

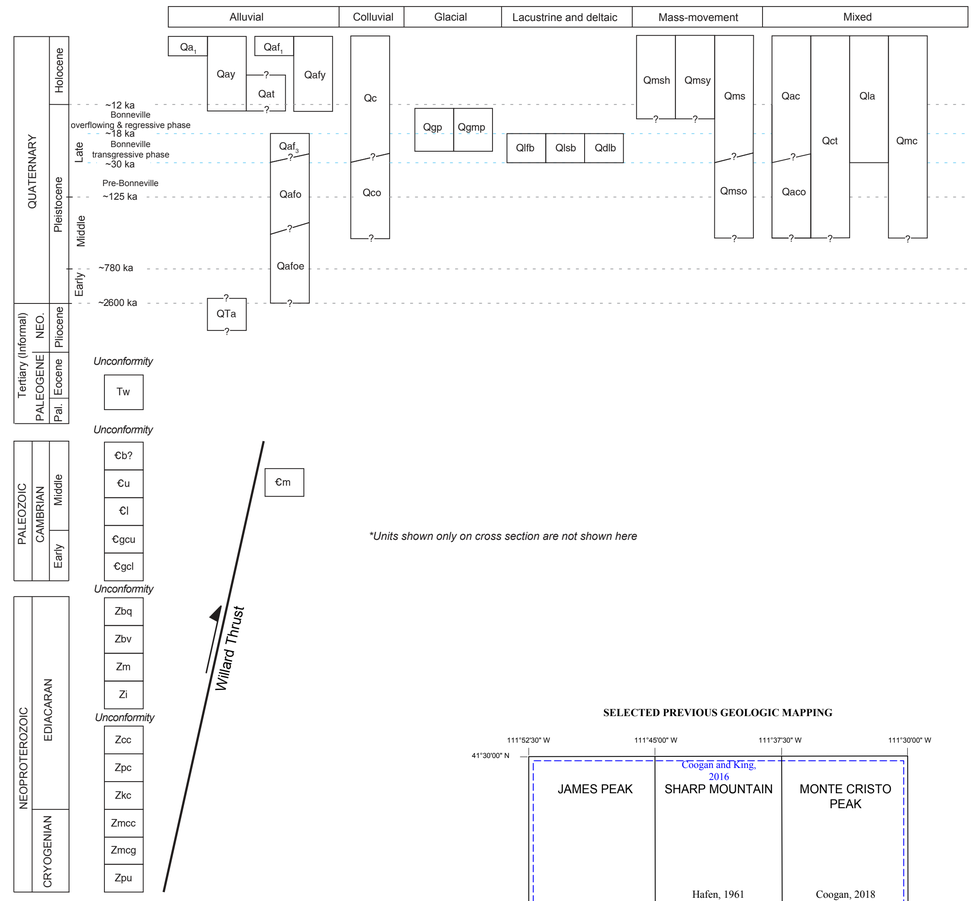
- Jtgu Twin Creek and Gypsum Spring Formations, undivided (cross section only)
- Jn Nugget Formation (cross section only)
- ₮ru Ankareh, Thaynes, Woodside, and Dinwoody Formations, undivided (cross section only)

GEOLOGIC SYMBOLS

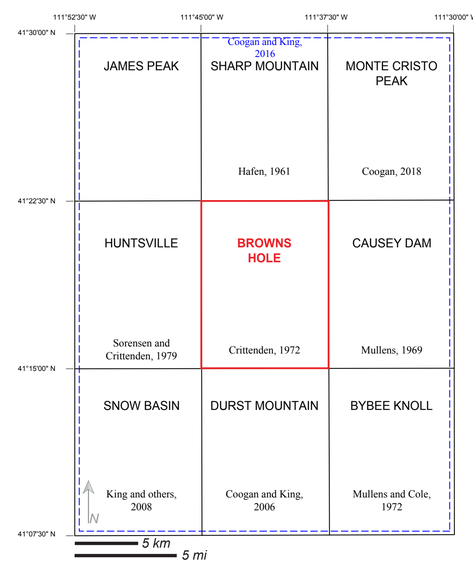
- Contact - dashed where approximately located; dotted where concealed
- Fault, unknown kinematics - dashed where approximately located; dotted where concealed; queried where existence and/or location uncertainty is high
- Normal fault - dashed where approximately located; dotted where concealed; ball and bar on downthrown hanging wall; queried where existence and/or location uncertainty is high; arrows show relative movement on cross section
- Normal fault, geophysical, gravity - data and location from Jordan and others (2019); concealed and very approximately located
- Thrust fault - dashed where approximately located; dotted where concealed; teeth on hanging wall; queried where existence and/or location uncertain; arrows show relative movement on cross section
- Lineament
- Headwall of glacial cirque
- Crest of asymmetrical glacial moraines; ticks on steep (ice) side
- Landslide scarp - ticks on down-dropped side
- Limestone marker bed in Kelley Canyon Formation on Plate 1 and cross section
- Anticline - dashed where approximately located; dotted where concealed
- Syncline - dashed where approximately located; dotted where concealed
- Bonneville shoreline (highstand) of Lake Bonneville; mapped at top of wave-cut bench; may coincide with geologic contacts
- A — A′ Cross section line
- Schematic tectonic foliation on cross section
- 12 Approximate strike and dip of inclined bedding
- 12 Strike and dip of inclined bedding
- 12 Strike and dip of bedding determined photogrammetrically
- 12 Strike and dip of overturned bedding
- Strike of approximately vertical bedding
- 12 Strike and dip of tectonic cleavage
- 12 Minor fold showing bearing and plunge of fold hinge
- 12 Strike and dip of inclined joint or fracture
- Strike of vertical joint or fracture
- 12 Strike and dip of inclined bedding from Crittenden (1972)
- 12 Strike and dip of overturned bedding from Crittenden (1972)
- Strike of approximately vertical bedding from Crittenden (1972)
- 12 Strike and dip of tectonoic cleavage from Crittenden (1972)
- 12 Dip and dip direction of fault from Crittenden (1972)
- Sinkhole
- Spring
- Water well (select)

See booklet for map unit descriptions, acknowledgments, and references.

CORRELATION OF MAP UNITS

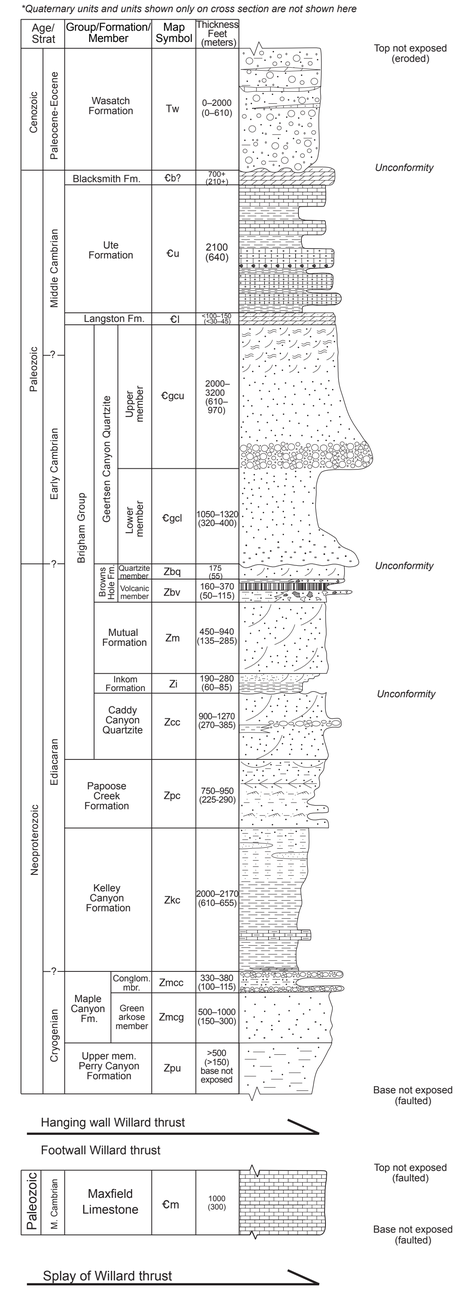


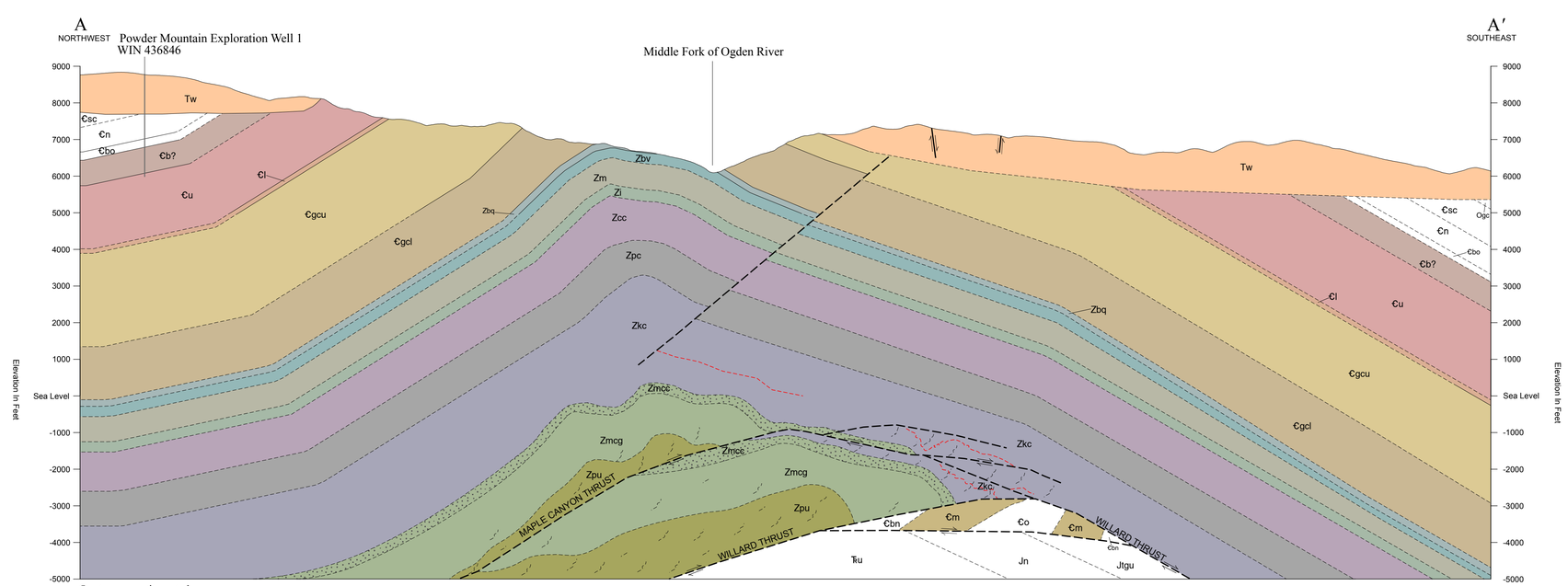
SELECTED PREVIOUS GEOLOGIC MAPPING



LITHOLOGIC COLUMN

**Quaternary units and units shown only on cross section are not shown here*





Quaternary units not shown.

Subsurface geology based on down plunge projection of geology mapped to the south in this quadrangle and neighboring areas mapped by Coogan and King (2016).

INTERIM GEOLOGIC MAP OF THE BROWNS HOLE QUADRANGLE, WEBER AND CACHE COUNTIES, UTAH

by

Zachary W. Anderson [1], Greg N. McDonald [1], Elizabeth A. Balgord [2], and W. Adolph Yonkee [2]

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Disclaimer

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OPEN-FILE REPORT 760
UTAH GEOLOGICAL SURVEY
UTAH DEPARTMENT OF NATURAL RESOURCES
2023

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INTRODUCTION

The Browns Hole quadrangle is in Weber and Cache Counties of northern Utah and covers the eastern part of Ogden Valley, a rapidly developing area of the Wasatch Range. The Middle and South Forks of the Ogden River bisect the quadrangle and are important watersheds and recreational areas to the communities of Ogden Valley and the Wasatch Front. The towns of Huntsville and Eden are just west of the quadrangle, unincorporated communities with year-round residents are present throughout the quadrangle, and numerous summer-cabin communities are present in the eastern part of the quadrangle. A portion of Powder Mountain ski resort, which draws year-round visitation and recreation, is present in the northwest corner of the quadrangle.

The quadrangle contains the Willard thrust, a major thrust fault with approximately 30 mi (50 km) of eastward displacement that was active during the Cretaceous-Eocene Sevier orogeny (Yonkee and others, 2019). In the quadrangle, the Willard thrust places Neoproterozoic through Ordovician strata in the hanging wall over a fault-bounded lozenge of Cambrian strata and footwall Jurassic and Triassic strata (see cross section on Plate 2). Neoproterozoic strata comprise a succession of mostly clastic rocks deposited during rifting of western North America and breakup of the supercontinent Rodinia (Yonkee and others, 2014). These rocks include the Cryogenian-age Perry Canyon and Maple Canyon Formations, and the Ediacaran-age Kelley Canyon Formation, Papoose Creek Formation, Caddy Canyon Quartzite, Inkom Formation, Mutual Formation, and Browns Hole Formation. The Browns Hole Formation is a sequence of interbedded volcaniclastic rock and basalt lava flows that provides the only radiometric age control in the quadrangle. Provow and others (2021) reported a ~610 Ma detrital apatite U-Pb age from volcaniclastic sandstone at the base of the formation, Crittenden and Wallace (1973) reported a 580 ± 14 Ma K-Ar hornblende age for a volcanic clast, and Verdel (2009) reported a 609 ± 25 Ma U-Pb apatite age for a basalt flow near the top of the formation. Cambrian strata in the hanging wall include a thick basal clastic sequence (Geertsen Canyon Quartzite) overlain by a thick sequence of interbedded limestone, shale, and dolomite (Langston, Ute, and Blacksmith Formations). Hanging wall rocks are deformed by Willard thrust-related structures, including the Browns Hole anticline, Maple Canyon thrust, and numerous smaller folds and minor faults. Footwall rocks of the Willard thrust include highly deformed Cambrian strata within a fault-bounded lozenge exposed in the southern part of the quadrangle, and Jurassic and Triassic rocks exposed just south of the quadrangle. The Paleocene-Eocene Wasatch Formation unconformably overlies older rocks and was deposited over considerable paleotopography developed during late stages of the Sevier orogeny. The southwest part of the quadrangle is cut by a southwest-dipping normal fault system that bounds the east side of Ogden Valley. This fault is interpreted to have experienced an early phase of slip during local late Eocene to Oligocene collapse of the Sevier belt and deposition of volcanic and volcaniclastic rocks (Norwood Tuff) exposed west of the quadrangle (Sorensen and Crittenden, 1979), and a younger phase of slip during Neogene Basin and Range extension (Zoback, 1983). Lacustrine deposits and shorelines of Pleistocene-age Lake Bonneville are present in the southwest corner of the quadrangle near the mouth of the South Fork of the Ogden River and record the highstand of Lake Bonneville (Oviatt, 2015). Pleistocene glacial deposits, present in the northwest corner of the map, are likely related to the Pinedale glaciation, commonly expressed by two moraine building episodes in the Wasatch Range (Quirk and others, 2020). Numerous incised alluvial deposits and geomorphic surfaces are present along major drainages and record pre- and post-Lake Bonneville aggradational and degradational alluvial and colluvial sequences. Mass-movement deposits, including historically active landslides, are present throughout the quadrangle.

Crittenden (1972) mapped the Browns Hole quadrangle at 1:24,000 scale, which provided an excellent foundation for the general stratigraphy and structure, but the 1972 map lacked important details of unconsolidated surficial units. As part of 1:62,500 scale mapping of the Ogden 30'x60' quadrangle, Coogan and King (2016) updated stratigraphic nomenclature, revised some contacts, and added more details for surficial units. For this map, we utilized new techniques for data acquisition and analysis to delineate surficial deposits, bedrock contacts, and faults more accurately and precisely. Mapping and field data collection were largely done in 2021–2022 using a combination of GPS-enabled tablets equipped with georectified aerial imagery (U.S. Department of Agriculture [USDA] National Agriculture Imagery Program [NAIP], 2009), orthoimagery (Utah Geospatial Resource Center [UGRC] State Geographic Information Database, 2018b, 2018c; 2021a, 2021b), and lidar data (UGRC State Geographic Information Database, 2006; 2011; 2013–2014; 2018a), previously published geologic maps, topographic maps, and applications for digital attitude collection. We also used hand-held GPS units, Brunton compasses, and field notebooks to collect geologic data. Field data were transferred to a Geographic Information System (GIS), where the map was compiled and completed.

MAP UNIT DESCRIPTIONS

SURFICIAL DEPOSITS

QUATERNARY-PLIOCENE (TERTIARY)

Alluvial Deposits

Qa_1 **Youngest stream alluvium and floodplain deposits** (Holocene) – Poorly to well sorted, pebble to cobble gravel with a matrix of sand, silt, and clay; deposited in channels; angular to rounded grains; composition depends on source area; crudely bedded; locally includes muddy overbank and organic-rich marsh deposits; mapped where the South Fork of the Ogden River enters Ogden Valley and active channels can be distinguished from adjacent, slightly elevated deposits; 0 to 20 feet (0–6 m) thick.

Qay **Younger stream alluvium and floodplain deposits** (Holocene to Late Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel in a matrix of sand, silt, and clay in channels, floodplains, and low terraces typically less than 10 feet (3 m) above modern channel; angular to subangular grains and clasts; composition depends on source area; locally includes muddy overbank and organic-rich marsh deposits; mapped along the major valley-bottom streams including the Middle and South Forks of Ogden River; 0 to 20 feet (0–6 m) thick.

Qat **Stream terrace deposits** (Holocene? to Late Pleistocene?) – Poorly to well-sorted pebbles to boulders in a matrix of sand, silt and clay; subangular to subrounded grains and clasts; poorly to moderately bedded; forms terraces about 5 to 10 feet (1–3 m) above modern streams and/or floodplains; typically 0 to 10 feet (0–3 m) thick.

QTa **High-level alluvial deposits** (Early Pleistocene? to Pliocene?) – Poorly sorted cobble/boulder gravel with a matrix of sand, silt, and clay; subangular to subrounded clasts; poorly bedded; eroded alluvial-terrace remnant deposits up to several hundreds of feet above modern drainages; surfaces commonly armored with boulder and cobble lag; mapped on surfaces developed on Tertiary Wasatch Formation (Tw) west of Beaver Creek, north of its confluence with the South Fork of the Ogden River; up to 50 feet (15 m) thick.

Qaf_1 **Youngest alluvial-fan deposits** (Holocene) – Poorly to moderately sorted, angular to subangular pebbles to boulders in a matrix of silt, sand, and minor clay; crudely stratified or massive; composition depends on source area; consists of debris flow and sheet flood deposits coalescing into small alluvial fans inset into younger alluvial fan (Qafy); deposits grade to active stream channels; 0 to 20 feet (0–6 m) thick.

Qafy **Younger alluvial-fan deposits** (Holocene to Late Pleistocene) – Poorly to moderately sorted, angular to subangular pebbles to boulders in a matrix of silt, sand, and minor clay; crudely stratified or massive; composition depends on source area; includes debris flows, debris floods, and channel deposits that form fan surfaces at the mouths of active drainages; may grade to active stream channels or Lake Bonneville deposits; 0 to 30 feet (0–9 m) thick.

Qaf_3 **Level-3 alluvial-fan deposits related to transgressive phase of Lake Bonneville** (Late Pleistocene) – Poorly to moderately sorted, crudely- to non-stratified pebbles to boulders with a matrix of sand, silt, and minor clay; clasts angular to subrounded and commonly matrix supported; deposited principally by debris flows, sheet floods, and channels that form alluvial fans at the mouths of drainages; unit grades to Lake Bonneville transgressive or highstand shoreline deposits or is at a height above modern surfaces consistent with correlative deposits; unit is both incised and covered by younger alluvial deposits; thickness less than 30 feet (9 m).

Qafo **Older alluvial-fan deposits** (Late? to Middle Pleistocene?) – Poorly to moderately sorted pebbles to boulders with a matrix of silt, sand, and clay; subangular to subrounded clasts; poorly bedded; fan surfaces commonly covered by a cobble or boulder lag with the clasts embedded into the fan surface; fans typically eroded and incised by younger fans and drainages; characteristic reddish, clay-rich matrix is common; locally contains well-developed calcium carbonate soil horizons; remnant surfaces near Middle Fork of Ogden River are graded to elevations above Lake Bonneville highstand shoreline, but elsewhere this cross-cutting relationship is unclear and may overlap with Bonneville deposits; commonly mapped at lower elevations than Qafoe, but overlap in some locations; 10 to 50 feet (3–15 m) thick.

Qafoe **Eroded older alluvial-fan deposits** (Middle? to Early Pleistocene?) – Poorly sorted cobble and boulder gravel with a matrix of sand, silt, and clay; subangular to rounded clasts; poorly bedded; surface may be cobble/boulder-armored; deposits are elevated, isolated remnant fan or alluvial deposits; deposits may lack alluvial-fan morphology and are typically truncated/inset by younger alluvial deposits; commonly graded to higher elevations than older alluvial fan deposits (Qafo) and lower elevations than high-level alluvial deposits (QTa), but may overlap in some locations; 0 to 50 feet (0–15 m) or more thick.

Colluvial Deposits

Qc **Colluvial deposits** (Holocene to Late Pleistocene?) – Poorly sorted silt, sand, gravel, clay, cobbles, and boulders; angular to subangular clasts; rounded clasts derived from Tertiary Wasatch Formation (Tw) are common; massive to poorly bedded; composition depends on local bedrock source; mapped on moderate to steep slopes; includes slope-wash and soil creep deposits and may include local mass-movement and talus deposits; includes residual deposits developed on Wasatch Formation; 6 to 50 feet (2–15 m) thick.

Qco **Older colluvial deposits** (Late? to Middle Pleistocene?) – Poorly sorted silt, sand, gravel, clay, cobbles, and boulders; angular to subangular clasts; rounded clasts derived from Tertiary Wasatch Formation (Tw) are present; non-bedded; mapped on elevated ridges below quartzite-bearing bedrock units where cobbles and boulders cover bedrock; mapped only on rounded, elevated ridges below resistant bedrock units Zcc and €gcl, where active colluvial deposition has ceased; 6 to 50 feet (2–15 m) thick.

Glacial Deposits

Qgp **Glacial deposits, undivided, Pinedale age** (Late Pleistocene) – Non-stratified, poorly sorted clay- to boulder-size sediment; glacial till and a component of outwash; primarily derived from rounded cobbles and boulders of Wasatch Formation (Tw); rare angular clasts derived from local Cambrian units; mapped as undivided glacial deposits because deposits lack distinct geomorphic shapes of end, recessional, and lateral moraines; likely deposited during Pinedale glaciation, which roughly correlates to the colder and wetter Marine Isotope Stage (MIS) 2 (14 to 29 ka; Lisiecki and Raymo, 2005); maximum ice extent in the Wasatch Range occurred between 17.5 and 22 ka (Laabs and Munroe, 2016; Quirk and others, 2018, 2020); estimated thickness up to 50 feet (15 m).

Qgmp **Glacial moraine till, Pinedale age** (Late Pleistocene) – Till of ground, end, recessional, and lateral moraines; till is non-stratified, poorly sorted clay- to boulder-size sediment, primarily derived from rounded cobbles and boulders of Wasatch Formation; includes rare angular clasts locally derived from Cambrian units; mapped moraines have poorly to moderately developed soil and moderate moraine morphology; unit lacks sharp moraine morphology of other Pinedale age moraines in the Wasatch Range due to nature of source material (rounded clasts from Wasatch Formation); likely deposited during Pinedale glaciation, which roughly correlates to the colder and wetter MIS2 (14 to 29 ka; Lisiecki and Raymo, 2005); maximum ice extent in the Wasatch Range occurred between about 17.5 and 22 ka (Laabs and Munroe, 2016; Quirk and others, 2018, 2020); estimated thickness up to 120 feet (35 m).

Lacustrine and Deltaic Deposits

Qlfb **Lacustrine fine-grained deposits related to transgressive phase of Lake Bonneville** (Late Pleistocene) – Moderately to well-sorted and moderately bedded to thinly laminated clay, silt, and sand deposited during the transgression and highstand of Lake Bonneville; deposited in shallow to moderately deep water; typically overlies pre-Bonneville alluvium and may overlie middle Pleistocene Little Valley lake cycle deposits (Scott and others, 1983; Oviatt and others, 1999); 5 feet (2 m) thick or greater.

Qlsb **Lacustrine sand and gravel deposits related to transgressive phase of Lake Bonneville** (Late Pleistocene) – Moderately to poorly sorted, moderately to well-bedded sand and gravel with silt and clay; subangular to rounded clasts; deposited in transgressive Lake Bonneville nearshore environments; includes thin clay and silt interbeds; may grade laterally into Qlfb or Qdlb; typically less than 20 feet (6 m) thick.

Qdlb **Deltaic and lacustrine deposits related to transgressive phase of Lake Bonneville** (Late Pleistocene) – Moderately to well-sorted sand, gravelly sand, silty sand, and cobbles deposited in Lake Bonneville deltas and near shore as the

lake transgressed; subrounded to rounded clasts; moderately to well bedded; forms flat topped deposits of sediment; incised by modern drainages where the Middle and South Forks of the Ogden River entered Lake Bonneville; 0 to 30 feet (0–9 m) thick.

Mass-Movement Deposits

Qmsh **Landslide deposits, historical movement** (Holocene to Late Pleistocene?) – Unsorted to poorly sorted clay- to boulder-sized material in slides, slumps, flows, and landslide complexes; generally characterized by hummocky topography, head, lateral, and/or internal scarps, and chaotic bedding in displaced blocks; composition reflects local sources; includes landslides having historical movement; thickness highly variable, up to 30 feet (9 m).

Qmsy Y**ounger landslide deposits** (Holocene to Late Pleistocene?) – Poorly sorted clay- to boulder-sized material in slides, slumps, flows, and landslide complexes; generally characterized by hummocky topography, head, lateral, and/or internal scarps, and chaotic bedding in displaced blocks; composition reflects local sources; morphology suggests post-Lake Bonneville movement with relatively sharp and pronounced landslide deformation features and may include parts that are historic and active; thickness highly variable, up to 60 feet (20 m).

Landslides of all ages may continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded (Ashland, 2003). Vegetation and widespread colluvium may conceal unmapped landslides, and more detailed imaging techniques such as lidar may reveal evidence of creep or shallow landslides. Understanding the location, age, and stability of landslides and slopes requires detailed geotechnical investigations.

Qms **Landslide deposits** (Holocene to Late Pleistocene?) – Poorly sorted clay- to boulder-sized material in slides, slumps, flows, and landslide complexes; generally characterized by hummocky topography, head, lateral, and/or internal scarps, and chaotic bedding in displaced blocks; composition reflects local sources; morphology can become more subdued with increasing age and/or rate of movement; mapped where relative age cannot be distinguished or where landslide complexes have parts with different ages and/or rates of activity; thickness highly variable, up to 60 feet (20 m).

Landslides of all ages may continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded (Ashland, 2003). Vegetation and widespread colluvium may conceal unmapped landslides, and more detailed imaging techniques such as lidar may reveal evidence of creep or shallow landslides. Understanding the location, age, and stability of landslides and slopes requires detailed geotechnical investigations.

Qmso **Older landslide deposits** (Late? to Middle Pleistocene?) – Poorly sorted clay- to boulder-sized material in slides, slumps, flows, and landslide complexes; generally characterized by hummocky topography, head, lateral, and/or internal scarps, and chaotic bedding in displaced blocks; composition reflects local sources; morphology can become more subdued with increasing age and/or rate of movement; mapped where landslide deposits have a more subdued morphology; thickness highly variable, up to 120 feet (40 m).

Landslides of all ages may continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded (Ashland, 2003). Vegetation and widespread colluvium may conceal unmapped landslides, and more detailed imaging techniques such as lidar may reveal evidence of creep or shallow landslides. Understanding the location, age, and stability of landslides and slopes requires detailed geotechnical investigations.

Mixed-Environment Deposits

Qac **Undivided alluvial and colluvial deposits** (Holocene to Late Pleistocene?) – Unsorted to variably sorted silt, sand, gravel, clay, cobbles, and boulders in variable proportions and roundness; includes stream and fan alluvium, colluvium, sheetwash deposits, and locally mass-movement deposits that are too small to map separately at map scale; typically mapped along drainages bounded by hillslopes where colluvium grades into alluvium without distinct break in slope and in smaller drainages lacking flat bottoms or too small to subdivide at map scale; 0 to 20 feet (0–6 m) thick.

Qaco **Undivided older alluvial and colluvial deposits** (Late? to Early Pleistocene?) – Unsorted to variably sorted silt, sand, gravel, clay, cobbles, and boulders in variable proportions and roundness; includes stream and fan alluvium, colluvium, sheetwash deposits, and locally mass-movement deposits that are too small to map separately at map

scale; typically mapped in drainage basins and moderate to steep slopes; often incised up to tens of feet by ephemeral channels and may be inset with younger alluvium; 20 feet (0–6 m) thick or greater.

Qct **Undivided colluvium and talus deposits** (Holocene to Middle Pleistocene?) – Unsorted to variably sorted sand, gravel, clay, cobbles, and boulders in variable proportions and roundness; includes scree-covered slopes and talus cones; mapped on and below steep, rocky terrain associated with resistant bedrock units; differentiated from Qmc by considerably less soil and vegetation; 0 to 20 feet (0–6 m) thick.

Qla **Undivided lacustrine and alluvial deposits** (Holocene to Late Pleistocene) – Poorly to moderately sorted silt, sand, clay, and gravel; subangular to rounded clasts; moderately to well bedded; includes Lake Bonneville-age transgressional deposits below and near the highstand shoreline and where post-Bonneville stream alluvium overlies lacustrine deposits; 1 to 10 feet (0.3–3 m) thick.

Qmc **Undivided mass-movement and colluvial deposits** (Holocene to Middle Pleistocene?) – Poorly sorted to unsorted, mostly clay, silt, sand, gravel, cobbles, and boulders; angular to rounded clasts; non-bedded; mapped on slopes where individual landslides, slumps, slopewash, and soil creep are difficult to distinguish from one another; often characterized by hummocky slopes composed of numerous slumps of various sizes and ages; includes soil creep, talus, slopewash, and debris-flow deposits but lacks clear landslide scarps and lateral margins to allow separate mapping; typically forms on slopes overlying clay-bearing, landslide-prone bedrock units; 0 to 40 feet (0–12 m) thick.

Unconformity

PALEOGENE (TERTIARY) ROCKS

PALEOGENE

Tw, Tw?

Wasatch Formation (Eocene to Paleocene) – Moderate reddish-orange to pale yellowish-orange, cobble to boulder conglomerate with varying amounts of mudstone and sandstone; forms cobble- and boulder-strewn slopes but does not crop out; unconsolidated to consolidated claystone, sandstone, limestone, and dolomite reported in lithologic logs from water wells drilled < 1 mile (0.6 km) west of the western quadrangle border near Powder Mountain ski resort (see logs for Well Identification Number [WIN] 436850 and 436926, Utah Division of Water Rights well database [UDWR], 2022); clasts are tan, gray, purple, and green quartzite and well-indurated sandstone, sourced dominantly from the Brigham Group; lower contact is sharp, unconformable; deposited over considerable paleotopography; queried where unit designation uncertain and may be older colluvium or alluvium; may include Cretaceous-age (Maastrichtian) deposits of the Hams Fork Member of the Evanston Formation in the southeast part of the map, as mapped by Coogan and King (2016); 0 to over 2000 feet (0–610+ m) thick.

Unconformity

HANGING WALL ROCKS OF WILLARD THRUST SHEET

PALEOZOIC

ORDOVICIAN

Ogc **Garden City Formation** (Ordovician) – On cross section only. Mainly limestone and dolomite with interbedded siltstone and intraformational “flat-pebble” limestone conglomerate; thickness approximately 500 feet (152 m) (Mullens, 1969).

Unconformity

CAMBRIAN

Ꞓsc **St. Charles Formation** (Late Cambrian) – On cross section only. Main body is dolomite with minor sandstone; basal Worm Creek Quartzite Member is interbedded sandstone, quartzite, and dolomite. In the northeast corner of the neighboring Huntsville quadrangle, the Bloomington well (WIN 441068 [UDWR, 2022]) penetrated an incomplete thickness of 485 feet (148 m); total thickness reported in the Huntsville quadrangle is 490 to 823 feet (150–251 m) (Sorensen and Crittenden, 1979).

Ꞓn **Nounan Formation** (Late Cambrian) – On cross section only. Dolomite and some limestone. Powder Mountain Exploration well 1 (WIN 436846 [UDWR, 2022]) penetrated an incomplete thickness of 565 feet (170 m), total thickness reported in neighboring Huntsville quadrangle is 495 to 760 feet (150–230 m) (Sorensen and Crittenden, 1979).

Ꞓbo **Bloomington Formation, undivided** (Middle Cambrian) On cross section only. Thinly bedded shale interbedded with shaley limestone and zones of medium bedded limestone. Unit is likely equivalent to Calls Fort Member of Bloomington Formation. Powder Mountain Exploration well 1 (WIN 436846[UDWR, 2022]) penetrated a total thickness of 230 feet (70 m), total thickness reported in neighboring Huntsville quadrangle is 75 to 295 feet (23–90 m) (Sorensen and Crittenden, 1979).

Ꞓb? **Blacksmith Formatio**n (Middle Cambrian) – Light-gray to bluish-gray, thin- to medium-bedded crystalline dolomite and limestone with minor shale partings and laminations; forms crumbling ridges that weather to a dark gray; fresh surfaces locally have a fetid odor; lower contact is conformable and mapped at slope break where less resistant limestone and shale of Ute Formation change to resistant dolomite and limestone; queried because thickness and exposures are limited within the quadrangle; mapped as undivided Ute and Blacksmith Limestones by Crittenden (1972); mapped as middle limestone member of Bloomington Formation by Coogan and King (2016); Powder Mountain Exploration well 1 (WIN 436846 [UDWR, 2022]) penetrated 710 feet (215 m) of dolomite and limestone between shaley limestone intervals, which was reported as Middle Member of Bloomington Formation, but we interpret as Blacksmith Formation; outcrop pattern in South Fork of Ogden River suggests minimum of about 700 feet (210 m) thick; top not exposed in quadrangle.

Ꞓu **Ute Formation** (Middle Cambrian) – Light-gray to grayish-blue, thin- to medium-bedded limestone with interbedded shaley limestone and dark greenish brown to reddish-orange fissile shale; limestone beds commonly contain twiggy bodies (as described in Lochman-Balk [1976] and Yonkee and Lowe [2004]), bioturbation and fossil hash; resistant packages of medium-bedded limestone commonly oncolitic; marker interval about 600 feet (185 m) above base contains abundant trilobites from biozone *Ehmaniella* in beds of minor oolitic limestone, intraclast "flat-pebble conglomerate," and thinly bedded gray limestone; Rigo (1968) reported *Glossopleura* sp. from the basal Ute Formation in neighboring Huntsville quadrangle; shaley limestone is common with ribbons of tan to yellow shale; forms steep slopes with cliffs and ridges of limestone; top of unit contains karsts beneath the Wasatch Formation (Tw); lower contact conformable and mapped at first shale above Langston Formation; mapped by Crittenden (1972) as Ute and Blacksmith Limestones, undivided; we included resistant limestone beds that Coogan and King (2016) mapped as queried Blacksmith Formation because they are not dolomite, but rather oncolitic limestone within an overall shaley limestone sequence; thickness is about 2100 feet (640 m) near South Fork of Ogden River, and about 1700 feet (520 m) on the northwest side of Middle Fork of Ogden River.

Ꞓl **Langston Formation** (Middle Cambrian) – Light to dark orange-brown weathering sandy dolomite and minor limestone; light- to dark-gray on fresh surfaces; medium bedded with planar and cross-bedded laminae; bedding commonly obscured by dolomitic alteration; lower part forms a prominent dark brown cliff south of South Fork of Ogden River, elsewhere forms recessive slopes and is commonly poorly exposed; lower contact conformable and gradational; about 150 feet (45 m) thick near South Fork of Ogden River; not exposed but likely less than 100 feet (30 m) thick in northwest part of quadrangle.

Ꞓgcu **Upper member of Geertsen Canyon Quartzite of Brigham Group** (Early to Middle Cambrian) – Dominantly grayish-yellow to grayish-orange, fine- to medium-grained, well-sorted, well-rounded, quartz arenite; medium- to thick-bedded with trough and planar tabular cross-beds with scoured bases; top part contains intervals of siltstone up to 3 feet (1 m) thick; lower part contains increasing abundance of coarse to very coarse sandstone and matrix- to clast-supported pebble to small cobble conglomerate with well-rounded clasts of red sandstone, tan quartzite, reddish chert, and white quartz; generally very resistant, forms broken cliffs and steep slopes; lower contact is conformable

and placed at base of 50- to 200-foot (15–65 m) thick pebble conglomerate interval that commonly forms lowest cliff band and marks the change from more arkosic sandstone below to quartz arenite above; Early Cambrian age based on *Skolithos* and *Diplocraterion* trace fossils present in upper part, age of lower part not constrained; approximately 2000 to 3200 feet (610–970 m) thick.

Ꞓgcl **Lower member of Geertsen Canyon Quartzite of Brigham Group** (Early Cambrian) – Moderate red to very pale orange, fine-grained to granule, subrounded to angular, poorly sorted sandstone with minor pebble conglomerate; subfeldspathic to feldspathic arenite (arkose) with feldspar abundance decreasing up section and quartz increasing; feldspar grains locally up to 0.4 inch (1 cm) in length; medium bedded with beds containing cross and planar laminae as well as massive beds; forms slopes with upper part commonly poorly exposed; lacks trace fossils; lower contact is sharp, disconformable, and may represent the Cambrian-Precambrian boundary; age is poorly constrained; approximately 1050 to 1320 feet (320–400 m) thick.

Unconformity

NEOPROTEROZOIC

Zbq **Quartzite member of Browns Hole Formation of Brigham Group** (Neoproterozoic, Ediacaran) – Very pale orange to pale yellowish-orange quartz arenite; thin- to medium-bedded with laterally continuous beds; horizontal and trough-cross stratification and ripple laminations; fine- to very coarse grained, with subrounded to rounded grains; moderately sorted with occasional coarse grains; forms steep slopes and ledges, crops out moderately well; lower contact is abrupt but commonly poorly exposed; lower contact may be an unconformity (Provow and others, 2021), or conformable; about 175 feet (55 m) thick.

Zbv **Volcanic member of Browns Hole Formation of Brigham Group** (Neoproterozoic, Ediacaran) – Grayish-red-purple to moderate reddish-brown volcaniclastic sandstone and conglomerate interbedded with dark-gray basanite (basalt) flows; basal part contains sandstone and mudstone that are dark gray to blackish-red, thickly laminated to thinly bedded and fine-grained, moderate- to well-sorted, and quartzose to lithic with varying amount of chert and volcanic grains; grades up section into grayish-red-purple volcaniclastic sandstone and volcaniclastic pebble to cobble conglomerate; conglomerate clasts are dominantly rounded cobbles of porphyritic andesite, trachyandesite, and vesicular basalt (Verdel, 2009; Provow and others, 2021) with minor amount of maroon quartz sandstone and volcaniclastic sandstone; individual conglomerate beds are poorly sorted, structureless, up to 2 feet (60 cm) thick; laterally discontinuous aphanitic basanite flows near top of unit interbedded with recessive-weathering volcaniclastic sandstone and mudstone; hematitic staining common in volcaniclastic intervals; forms steep slopes and minor ledges; lower contact is sharp, conformable, and marked by appearance of hematite-stained sandstone with volcanic lithic grains, and color change from the lighter tan and reds of the Mutual Formation to dark reddish brown of the Browns Hole Formation; about 350 to 370 feet (105–115 m) thick near Middle Fork of Ogden River thinning to approximately 160 feet (50 m) thick near the South Fork of Ogden River.

This unit provides the only radiometric age control in the Brigham Group in northern Utah. Crittenden and Wallace (1973) reported a $^{40}Ar/^{39}Ar$ hornblende total gas age of 570 ± 14 Ma (corrected to 580 Ma for updated K-Ar decay constant, ± 2 sigma) for a trachyte clast from the volcaniclastic conglomerate. The total gas age, however, does not account for potential argon loss and could yield an erroneously young age. Verdel (2009) reported a U-Pb apatite age of 609 ± 25 Ma (2 sigma) from a basalt flow near the top of the unit. Provow and others (2021) reported a maximum depositional age of 613 ± 12 Ma (2 sigma) based on U-Pb analysis of detrital apatite from a volcaniclastic sandstone about 30 feet (10 m) up section from the lower contact. They suggest the 613 Ma age is close to true depositional age based on textural properties of the apatite grains and mineralogical composition of the lithic grains within the sandstone.

Zm **Mutual Formation of Brigham Group** (Neoproterozoic, Ediacaran) – Pale-pink, grayish-red-purple, to dark red, medium- to very coarse grained, well-indurated quartzose sandstone interbedded with minor pebble conglomerate and dark reddish-purple argillite; weathers to darker shades of reddish purple; sandstone is moderately to poorly sorted with subrounded grains; medium to thick bedded with horizontal and trough cross-stratification; forms prominent cliffs and ledges that are a major source of colluvium and talus in the area; lower contact is conformable and mapped at a major slope break where mixed argillite and sandstone of the Inkom Formation (Zi) become dominated by sandstone; Crittenden (1972) reported local feldspathic zones; approximately 940 feet (285 m) thick near Middle Fork of Ogden River, about 450 feet (135 m) thick near South Fork of Ogden River.

Zi **Inkom Formation of Brigham Group** (Neoproterozoic, Ediacaran) – Grayish-yellow to reddish-orange mudstone, sandstone, and minor pebble conglomerate; lower part is recessive yellowish-gray to dark yellowish-brown, thinly to thickly laminated mudstone and argillite; up section unit becomes silty argillite interbedded with moderate reddish-orange to moderate orange-pink, ripple-laminated sandstone and minor pebble conglomerate; sandstone is dominantly quartzose but locally contains feldspar and lithic grains; conglomerate clasts are greenish-gray sandstone; lower part generally forms slopes, steepening in the upper part; lower contact is sharp and unconformable; typically about 250 to 280 feet (75–85 m) thick, thinning to about 190 feet (60 m) south of South Fork of Ogden River where lower part includes channel sandstone and conglomerate up to 90 feet (30 m) thick (Levey and others, 1994).

Levy and others (1994) interpreted such channels to represent sea level drop during the Marinoan glaciation. Elsewhere in the quadrangle the base lacks major channels. Alternatively, the end of Marinoan glaciation may be recorded by a distinctive dolostone interval at the base of the Kelley Canyon Formation described below.

Unconformity

Zcc **Caddy Canyon Quartzite of Brigham Group** (Neoproterozoic, Ediacaran) – Very pale orange to grayish-orange to white sandstone with minor discontinuous beds of pale-red, clast-supported pebble conglomerate and purple argillite; sandstone is moderately well sorted, medium- to coarse-grained with subrounded grains; medium- to very thick bedded with local scoured bases and upward-fining sequences; horizontally and trough cross-stratified; forms cliffs and steep ledges that are a major source of colluvium and talus to slopes below; interfingering lower contact is mapped where sandstone becomes dominant up section, typically corresponding to major slope break, and marks the base of the Brigham Group (Crittenden and others, 1971; Christie-Blick, 1982; Crittenden and Sorensen, 1985); previous maps (Crittenden, 1972; Coogan and King, 2016) likely included a significant part of what we map as Papoose Creek Formation in the Caddy Canyon Quartzite; typically about 900 to 1000 feet (270–300 m) thick, thickening south of South Fork of Ogden River to about 1270 feet (385 m) thick.

Zpc, Zpc?

Papoose Creek Formation (Neoproterozoic, Ediacaran) – Rhythmically interbedded very pale orange quartzose sandstone, moderate to dark yellowish-brown mudstone, and moderate to dusky red argillite; sandstone is fine- to medium-grained with minor coarse-grained beds near top where unit interfingers with Caddy Canyon Quartzite; thin- to thick-bedded with distinct lenticular and flaser bedding and syneresis cracks; horizontal, ripple, and cross-laminations present; distinctive sequence of herringbone cross-stratification within lenticular sandstone bodies in upper one-third of formation; convolute bedding features in siltstone and argillite near top of unit are reminiscent of soft-sediment deformation including load casts or potentially biogenic features; forms steep slopes punctuated by small cliffs; lower contact is conformable, gradational, and mapped at a steepening in slope (up section) that corresponds to a lithologic change from argillite and sandstone below to dominantly sandstone above; queried where unit designation is uncertain due to poor exposures, structurally complex areas, or areas previously mapped as other units that were not field checked; approximately 750 to 950 feet (225–290 m) thick.

Thick veneers of colluvial and talus deposits (see units Qc, Qct, Qco, and Qmc) derived from overlying Zcc unit commonly obscure this interval, which is likely why Crittenden (1972) and Coogan and King (2016) described this interval as transitional between the Kelley Canyon Formation (Zkc) and Caddy Canyon Quartzite (Zcc) rather than mapping it as a separate unit. However, we have identified this interval as a separate unit in the quadrangle using lithofacies associations plus textural features identified in stereo aerial photographs, orthoimagery, and lidar data.

Zkc **Kelley Canyon Formation** (Neoproterozoic, Ediacaran) – Dominantly thinly to thickly laminated argillite with minor limestone, shaley limestone, and sandstone; base of formation contains up to 6 feet (2 m) of yellowish- to pinkish-gray dolomite with wavy to domal laminations and argillite; grayish-yellow to grayish-orange-pink limestone and shaley limestone present about 400 to 500 feet (130–160 m) above base (mapped as marker bed on plate 1); below limestone marker bed, argillite is typically grayish purple, above marker bed argillite is pale yellowish green; increasing amount of very pale orange to grayish-yellow, thin- to medium-bedded tabular layers of quartzose siltstone and sandstone near top; lower contact is sharp and represents a major flooding surface; prone to slope failures; approximately 2000 to 2170 feet (610–655 m) thick.

The laminated dolomite at the base of the Zkc is interpreted to be correlative with the Marinoan "cap carbonate" found globally in Neoproterozoic rocks overlying "Snowball Earth" glacial deposits, which marks the end of the Cryogenian and start of the Ediacaran Period at 635 Ma (Hoffman and others, 1998; Fairchild and Kennedy, 2007; Allen and Etienne, 2008; Le Heron and others, 2011). The dolomite interval in the basal Zkc has distinct stratigraphic and sedimentological characteristics similar to other Marinoan cap carbonates including laminations and mounded structures (Hoffman and others, 2007; Hoffman, 2011; Dehler and others, 2011), therefore we infer the Ediacaran-Cryogenian boundary at the base of the Kelley Canyon Formation. Our interpretations are preliminary and require further stratigraphic, sedimentologic, geochronologic, and isotopic work.

Zmcc **Conglomerate member of Maple Canyon Formation** (Neoproterozoic, Cryogenian) – Tri-part stratigraphic package of basal conglomeratic sandstone, medial argillite, siltstone, and sandstone, and upper conglomeratic sandstone; forms a prominent topographic pattern of ridge, swale, and ridge; basal and upper packages are well-indurated grayish-yellow coarse-grained quartzose sandstones and matrix- to clast-supported pebble conglomerate, medium- to thick-bedded, horizontal and trough cross-stratified; upper package locally contains abundant detrital garnet concentrated along base of cross-bed sets; upper package becomes finer grained and/or thins to northwest, whereas the lower package becomes finer grained and/or thins southeastward; conglomerate clasts are dominantly white vein quartz and white quartzite with minor light- to dark-red sandstone, greenish-gray sandstone, and red or black chert; medial package is grayish-yellow to moderate reddish orange argillite with grayish-orange siltstone and sandstone that crops out as poorly exposed recessive swales; lower contact sharp, conformable, commonly poorly exposed; Crittenden (1972) and Sorensen and Crittenden (1979) mapped each package within this unit as, in ascending stratigraphic order, Zmcc1, Zmcc2, and Zmcc3; composite thickness 330 to 380 feet (100–115 m).

Zmcg **Green arkose member of Maple Canyon Formation** (Neoproterozoic, Cryogenian) – Very pale orange to grayish-brown to very pale green, medium- to coarse-grained, subarkosic to quartzose sandstone; minor pebble conglomerate and light-green mudstone interbeds; sandstone is moderately sorted, contains subrounded to subangular grains of quartz, feldspar, lithic chert, and is medium- to thick-bedded with horizontal, planar, and trough cross-stratification; beds appear laterally continuous over the scale of exposures; secondary quartz veins common; generally poorly exposed and forms slopes commonly covered in sandstone blocks; mapped as "lower (green arkose) member of Maple Canyon Formation" by Coogan and King (2016); float from unit commonly masks upper part of Perry Canyon Formation making the identification and map placement of lower contact difficult; where exposed, lower contact is sharp and conformable; commonly deformed by minor folds due to proximity to thrust faults, so true stratigraphic thickness difficult to determine; map-based thickness on the northwest side of Middle Fork of Ogden River is ~ 1000 feet (300 m), but is likely structurally thickened; Crittenden (1972) reported 500 to 1000 feet (150–300 m) thick.

Zpu **Upper member of Perry Canyon Formation** (Neoproterozoic, Cryogenian) – Pale- to moderate-blue, thinly bedded argillite to phyllite and meta-siltstone with medial lens of thin- to medium-bedded, pale greenish yellow, arkosic psammite (meta-sandstone); commonly folded and foliated; forms slopes and is generally poorly exposed; prone to slope failures; originally mapped by Crittenden (1972) and Sorensen and Crittenden (1979) as the lowest member (argillite member) of the Maple Canyon Formation; mapped as upper member of formation of Perry Canyon by Coogan and King (2016); Balgord and others (2013) reported a maximum depositional age of <667 ± 5 Ma from U-Pb analyses on detrital zircons from lower one-third of the upper member in Perry Canyon (geographic location), the upper part of which likely correlates to this section; base not exposed in quadrangle; Crittenden (1972) reported a thickness of 500 feet (150 m), which should be considered a minimum; structurally thickened map pattern on southwest side of Middle Fork of Ogden River suggests thickness of ~750 feet (230 m).

FOOTWALL ROCKS OF WILLARD THRUST SHEET

CAMBRIAN

Ꞓbn **Bloomington and Nounan Formations, undivided** (Late to Middle Cambrian) – On cross section only. Bloomington Formation is dominantly olive to light-brown shale, thinly bedded blue-gray limestone, and interbedded silty limestone with intraformational conglomerate. Nounan Formation is dark-gray, medium-bedded dolomite and limestone. Sorensen and Crittenden (1979) reported a combined thickness of 570 to 1050 feet (173–320 m) in the adjoining Huntsville quadrangle.

Ꞓm **Maxfield Limestone** (Middle Cambrian) – Light- to dark-gray limestone and dolomite with interbedded brown argillaceous limestone; oncolitic, intraformational "flat-pebble conglomerate," oolitic, and cherty horizons present; twiggy structures common; tri-part stratigraphy of upper limestone and dolomite, medial shaley limestone, and lower limestone present in neighboring and nearby quadrangles (Sorensen and Crittenden, 1979; Yonkee and Lowe, 2004, McKean and others, in preparation); tri-part division not discernible here due to intense deformation beneath the Willard thrust; structural thickness approximately 1000 feet (300 m).

Ꞓo **Ophir Formation** (Middle Cambrian) – On cross section only. Micaceous to silty shale (or argillite) with minor limestone and sandstone. Total thickness approximately 600 to 900 feet (180–270 m) (Coogan and King, 2016).

Faulted contact

JURASSIC

Jtgu **Twin Creek and Gypsum Spring Formations, undivided** (Middle Jurassic) – On cross section only. Twin Creek Formation is dominantly gray miciritic to shaley limestone, with intervals of oolitic and fossiliferous limestone, minor red mudstone, and minor sandstone near the top of unit; total thickness as reported by Coogan and King (2016) is 2850 feet (870 m); only lower part of formation may be present due to footwall fault cutoff. Gypsum Spring Formation is red mudstone and sandstone with dolomite and anhydrite; total thickness as reported by Coogan and King (2016) is approximately 200 feet (60 m).

Unconformity

Jn **Nugget Formation** (Early Jurassic) – On cross section only. Orange to tan, cross-bedded, well-sorted, quartzose sandstone; 1100 to 1360 feet (335–415 m) thick (Coogan and King, 2016).

TRIASSIC

Ꞧu **Triassic Ankareh, Thaynes, Woodside, and Dinwoody Formations, undivided** (Triassic) – On cross section only. Includes, in descending stratigraphic order, Ankareh, Thaynes, Woodside, and Dinwoody Formations; total thickness is at least 3900 feet (1180 m) after Coogan and King (2016). Ankareh Formation is a mixture of red shale, siltstone, sandstone, and minor limestone; intraformational unconformity at base of Gartra Grit Member; total thickness near Devils Slide is 1250 to 1400 feet (380–425 m). Thaynes Formation is gray to tan siltstone, shale, and fossiliferous limestone; total thickness near Devils Slide approximately 1850 feet (565 m). Woodside Shale is dark-red siltstone, shale, and minor sandstone; total thickness about 550 to 650 feet (165–200 m). Dinwoody Formation is greenish-gray and tan calcareous siltstone and silty limestone; total thickness approximately 250 feet (75 m).

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