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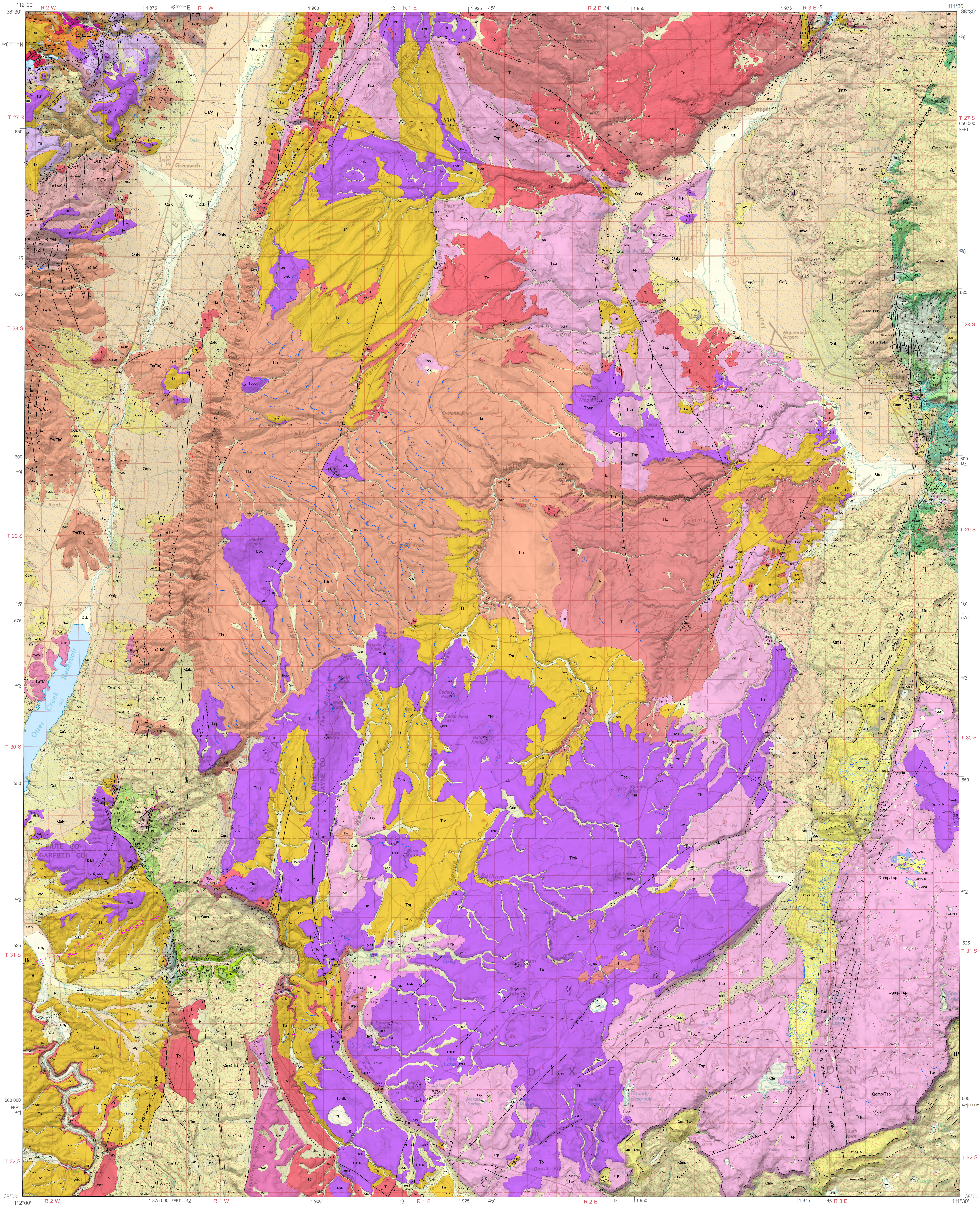
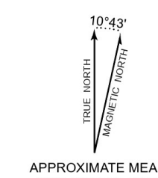
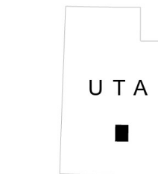


This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program through USGS STATEMAP award numbers G13AC00169 (2013), G14AC00214 (2014), G15AC00249 (2015), G18AC00202 (2019), and G20AC00244 (2020).



APPROXIMATE MEAN DECLINATION, 2023



MAP LOCATION

GEOLOGIC MAP OF THE WEST HALF OF THE LOA 30' X 60' QUADRANGLE, GARFIELD, PIUTE, AND WAYNE COUNTIES, UTAH

by

Robert F. Biek[1], Jeffrey G. Eaton[2], Peter D. Rowley[3], David B. Hacker[4], Stephen R. Mattox[5], Christopher Bailey[6], and David W. Marchetti[7]

2023

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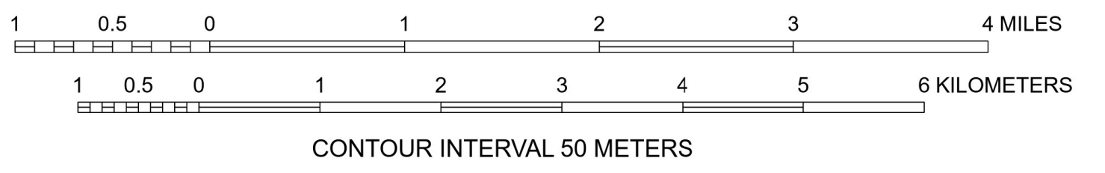

CONTOUR INTERVAL 50 METERS

Base from USGS Loa 30' x 60' Quadrangle (1980)
Shaded relief derived from USGS 10-meter NED
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1866

Program Manager: Stefan M. Kirby
Project Manager: Grant C. Willis and Donald L. Clark
GIS and Cartography: Basia Matyjasik
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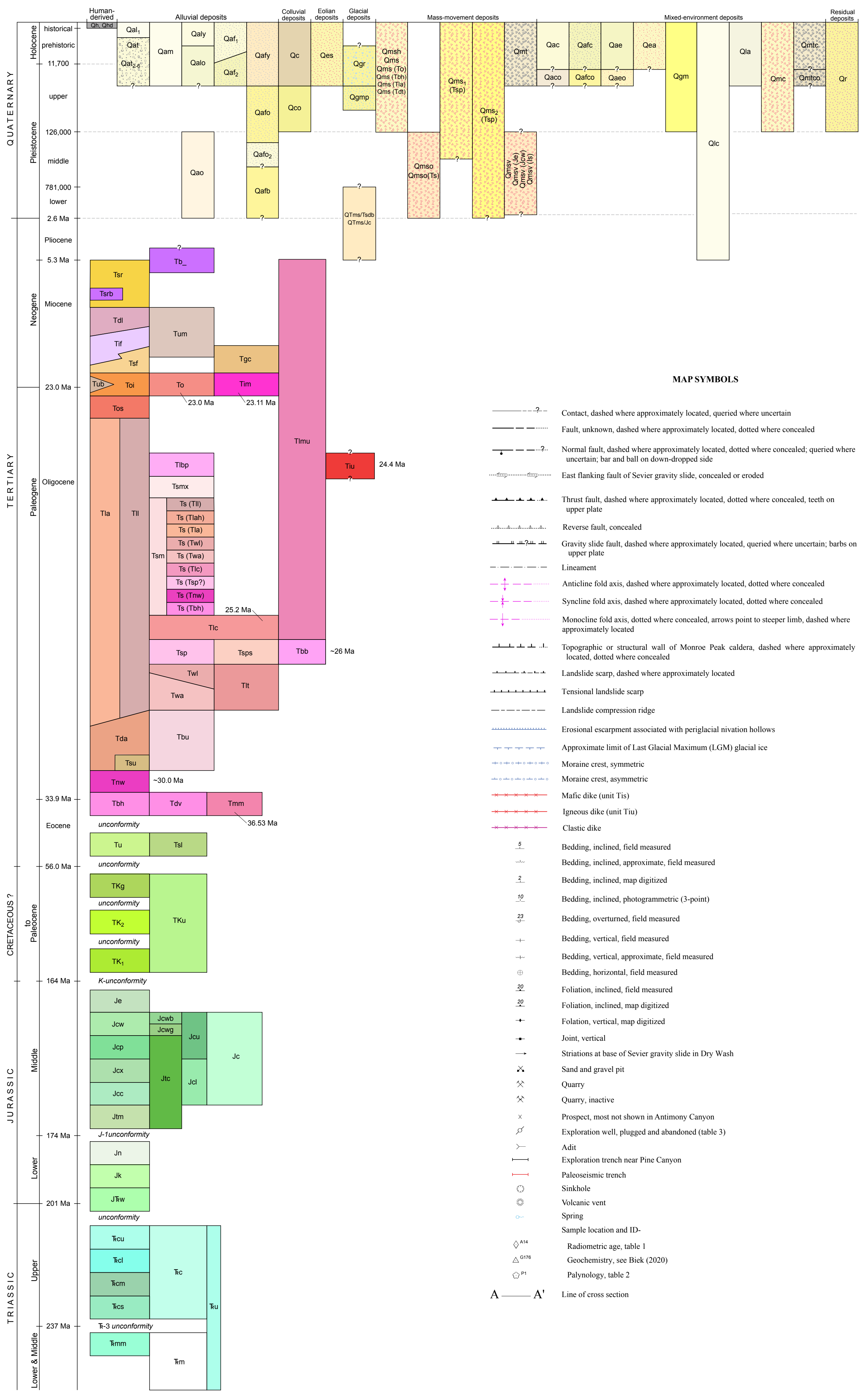
LIST OF MAP UNITS

Unit	Description
Qh	Artificial fill
Qhd	Disturbed land
Qal$_1$	Modern stream alluvium
Qat	Stream-terrace alluvium
Qat$_2$	Stream-terrace alluvium, level 2
Qat$_3$	Stream-terrace alluvium, level 3
Qat$_4$	Stream-terrace alluvium, level 4
Qat$_5$	Stream-terrace alluvium, level 5
Qat$_6$	Stream-terrace alluvium, level 6
Qam	Alluvial marsh deposits
Qaly	Young stream alluvium
Qalo	Old stream alluvium
Qao	Old alluvial deposits
Qaf$_1$	Young fan alluvium
Qaf$_2$	Middle fan alluvium
Qafy	Young and middle fan alluvium, undivided
Qafo	Old fan alluvium
Qafo$_2$	Older fan alluvium
Qafb	Oldest fan alluvium
Qc	Colluvium
Qco	Older colluvium
Qes	Eolian sand deposits
Qgr	Relict rock glaciers
Qgmp	Glacial till of Pinedale age
Qmsh	Landslide deposits, historical
Qms, Qms?	Landslide deposits
Qmso	Older landslide deposits
Qmso(Ts)	Older landslide blocks of Tertiary sedimentary strata
Qmsv	Landslide of Rabbit Valley
Qmsv(Je)	Landslide of Rabbit Valley (Entrada Sandstone component)
Qmsv (Jcw)	Landslide of Rabbit Valley (Winsor Member of the Carmel Formation component)
Qmsv(ls)	Landslide of Rabbit Valley (limestone component)
Qms(To)	Landslide blocks of Osiris Tuff
Qms(Tla)	Landslide blocks of volcanic rocks of Langdon Mountain
Qms(Tlc)	Landslide blocks of trachyte lava flows of Lake Creek
Qms$_1$ (Tsp)	Landslide blocks of volcanic rocks of Signal Peak
Qms$_2$ (Tsp)	Highly fractured landslide blocks of volcanic rocks of Signal Peak
Qms (Tbh)	Landslide block of Brian Head Formation
Qmt	Talus
Qac	Alluvium and colluvium
Qaco	Older alluvium and colluvium
Qafc	Fan alluvium and colluvium
Qafco	Older fan alluvium and colluvium
Qae	Alluvium and eolian sand
Qaeo	Older alluvium and eolian sand
Qea	Eolian sand and alluvium
Qgm	Glacial till and mass movement deposits, undivided
Qlc	Lacustrine and colluvial deposits
Qla	Lacustrine and alluvial deposits
Qmc	Landslides and colluvium
Qmtc	Talus and colluvium
Qmtco	Older talus and colluvium
Qr	Residual deposits
Qc/To	Colluvium over Osiris Tuff
Qc/Tsp	Colluvium over volcanic rocks of Signal Peak
Qac/Tsp	Mixed alluvium and colluvium over volcanic rocks of Signal Peak
Qgmp/ Tsp	Glacial till of Pinedale age over volcanic rocks of Signal Peak
Qgmp/ QTls	Glacial till of Pinedale age over limestone
Qgmp/ Tbbl	Glacial till of Pinedale age over basaltic lava flows of Bluebell Knoll
Qgmp/ Tbblc	Glacial till of Pinedale age over basaltic cinders of Bluebell Knoll
QTms (Tsdb)	Older landslide deposits of Tertiary sedimentary strata, Dipping Vat Formation, and Three Creeks Tuff Member of Bullion Canyon Volcanics
QTms/Jc	Older landslide deposits over Carmel Formation
Tv	Tertiary volcanic rocks, undivided
Tb	Basaltic lava flows, undivided
Tba	Basaltic andesite lava flow
Tbak	Basaltic lava flows of Abes Knoll
Tban	Basaltic lava flows of Antimony
Tbbak	Basaltic lava flows of Bald Knoll
Tbbp	Basaltic lava flows of Big Point
Tbbk	Basaltic lava flows of Burnt Knoll
Tbbl	Basaltic lava flows of Bluebell Knoll
Tbbu	Basaltic lava flows of The Buttes
Tbcp	Basaltic lava flows of Cedar Peak
Tben	Basaltic lava flows of Elsies Nipple*
Tbfl	Basaltic lava flows of Fish Lake
Tbfk	Basaltic lava flows of Flossie Knoll
Tbif	Basaltic lava flows of Indian Flat
Tbl	Basaltic lava flows of Loa
Tblslk	Basaltic lava flows of Lost Spring Knoll and Lost Knoll
Tbnp	Basaltic lava flows of Nicks Point
Tbpk	Basaltic lava flows of Parker Knoll
Tbpp, Tbpp?	Basaltic lava flows of Pine Peaks
Tbpl	Basaltic lava flows of Pollywog Lake
Tbrk	Basaltic lava flows of Red Knoll
Tbsk	Basaltic lava flows of Smooth Knoll
Tbtk	Basaltic lava flows of Timbered Knoll
Tis	Mafic dike
Tsr, Tsr?	Sevier River Formation
Tsrb	Basaltic lava flows in the Sevier River Formation
Tum	Upper moat sediments
Tdl	Dacite of Lower Box Creek Reservoir
Tim	Intrusive rocks of the Monroe Peak caldera
Tif	Lava flows of Indian Flat
Tifh	Lava flows of Indian Flat, hydrothermally altered
Tsf	Volcanic rocks of Sage Flat
Tsfh	Volcanic rocks of Sage Flat, hydrothermally altered
Tgc	Volcanic rocks of Greenwich Creek
Tub	Volcanic rocks of Upper Box Creek Reservoir
Tubh	Volcanic rocks of Upper Box Creek Reservoir, hydrothermally altered
Toi	Osiris Tuff, intracaldera facies
Toih	Osiris Tuff, intracaldera facies, hydrothermally altered
To	Osiris Tuff, outflow facies
Tos	Sandstone and conglomerate associated with the Osiris Tuff
Tlmu	Trachyte lava flows of Lake Creek, alluvial, lacustrine, and mass-movement strata related to Sevier gravity slide, breccia of Big Point, and Sevier River Formation, undivided
qtz	Quartz
Tiu	Breccia of Pine Canyon
Tlbp	Breccia of Big Point
Tsmx	Alluvial, lacustrine, and mass-movement strata eroded from Sevier gravity slide
Tsm	Sevier megabreccia, undivided
Tsm?	Sevier megabreccia, undivided?
Ts(Tll)	Sevier megabreccia, volcanic rocks of Langdon Mountain, lava flow facies component
Ts(Tlah)	Sevier megabreccia, volcanic rocks of Langdon Mountain, alluvial facies hydrothermally altered component
Ts(Tla)	Sevier megabreccia, volcanic rocks of Langdon Mountain, alluvial facies component
Ts(Twl)	Sevier megabreccia, volcanic rocks of Willow Spring, lava flow facies component
Ts(Twa)	Sevier megabreccia, volcanic rocks of Willow Spring, alluvial facies component
Ts(Tlt)	Sevier megabreccia, volcanic rocks of Little Table component
Ts(Tlc)	Sevier megabreccia, trachyte lava flows of Lake Creek component
Ts(Tsp?)	Sevier megabreccia, volcanic rocks of Signal Peak component?
Ts(Tnw)	Sevier megabreccia, Wah Wah Springs Formation component
Ts(Tbh)	Sevier megabreccia, Brian Head Formation component
Tll	Volcanic rocks of Langdon Mountain, lava flow facies
Tla	Volcanic rocks of Langdon Mountain, alluvial facies
*Tlah	Volcanic rocks of Langdon Mountain, alluvial facies, hydrothermally altered component
Tlc	Trachyte lava flows of Lake Creek
Tda	Mount Dutton Formation, alluvial facies
Tdlt	Mount Dutton Formation, local ash-flow tuff
*Twl	Volcanic rocks of Willow Spring, lava flow facies
*Twa	Volcanic rocks of Willow Spring, alluvial facies
*Tlt	Volcanic rocks of Little Table
Tsps	Volcanic rocks of Signal Peak, sedimentary strata
Tsp	Volcanic rocks of Signal Peak
Tbb, Tbb?	Buckskin Breccia
*Tsdb	Tertiary sedimentary strata, Dipping Vat Formation, and Three Creeks Tuff Member of the Bullion Canyon Volcanics, undivided
Tbu	Bullion Canyon Volcanics, undivided
Tsu, Tsu?	Tertiary sedimentary strata, upper unit
Tnw, Tnw	Wah Wah Springs Formation of Needles Range Group
Tmm, Tmm?	Volcanic rocks of Mill Meadow Reservoir
Tdv	Dipping Vat Formation
*Tbh	Brian Head Formation
Tsl	Tertiary sedimentary strata, lower unit
Tu	Fluvial and lacustrine strata of Antimony Canyon
TKu	Cretaceous-Tertiary strata, undivided
TKg	Conglomerate unit
TK$_2$	Sandstone and conglomerate unit
TK$_1$	Lower unit
K, K?	Cretaceous rocks, undivided
Je	Entrada Sandstone
Jc	Carmel Formation
Jcu	Carmel Formation, Winsor and Paria River Members, undivided
Jcw	Carmel Formation, Winsor Member
Jcwb	Carmel Formation, Winsor Member, banded subunit
Jcwg	Carmel Formation, Winsor Member, gypsiferous subunit
Jcp	Carmel Formation, Paria River Member
Jcl	Carmel Formation, Crystal Creek and Co-op Creek Limestone Members, undivided
Jcx	Carmel Formation, Crystal Creek Member
Jcc	Carmel Formation, Co-op Creek Limestone Member
Jtc	Thousand Pockets and Judd Hollow Members of Carmel Formation and Temple Cap Formation, undivided
Jtm	Temple Cap Formation, Manganese Wash Member
Jn	Navajo Sandstone
Jk	Kayenta Formation
JȾw	Wingate Sandstone
Ⱦu	Chinle and Moenkopi Formations, undivided
Ⱦc	Chinle Formation, undivided
Ⱦcu	Chinle Formation, upper slope former (Owl Rock Member and upper part of the Petrified Forest Member)
Ⱦcl	Chinle Formation, lower slope former (lower Petrified Forest Member and Mossback Member)
Ⱦcm	Chinle Formation, Monitor Butte Member
Ⱦcs	Chinle Formation, Shinarump Member
Ⱦm	Moenkopi Formation, undivided
Ⱦmm	Moenkopi Formation, Moody Canyon Member
P	Permian rocks, undivided
IP	Pennsylvanian rocks, undivided

* Only used as stacked or combined units.

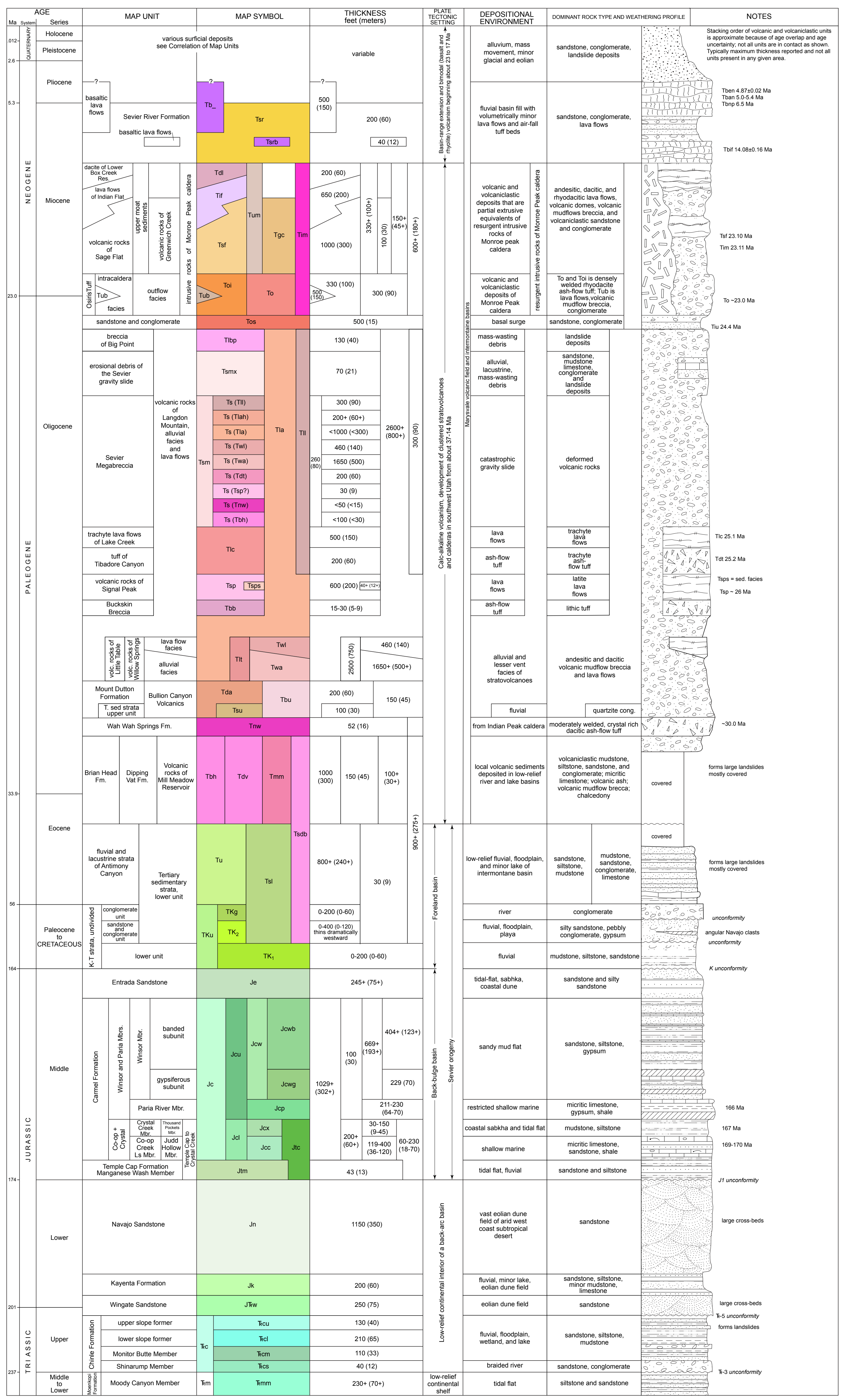
CORRELATION OF MAP UNITS

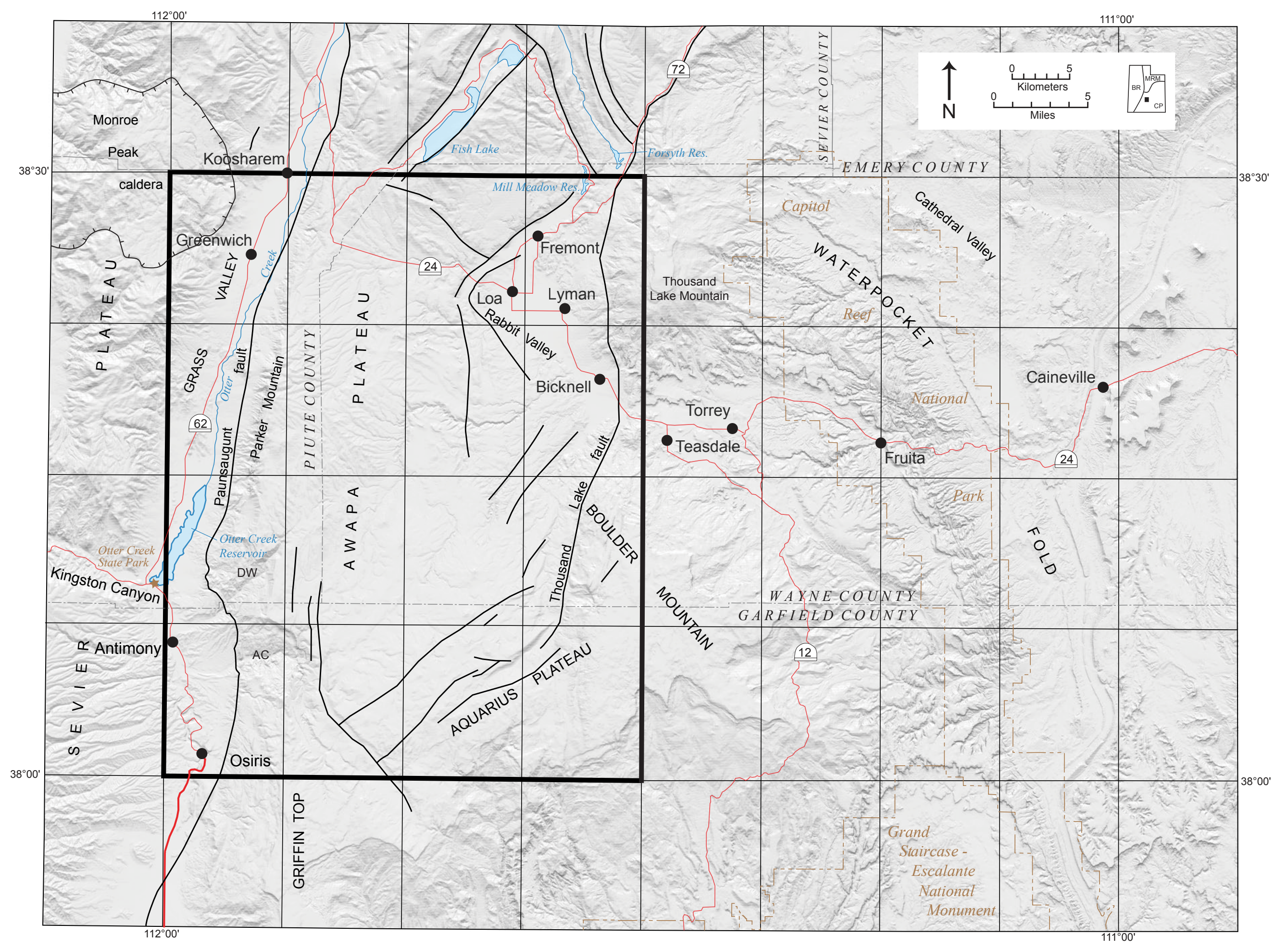


MAP SYMBOLS

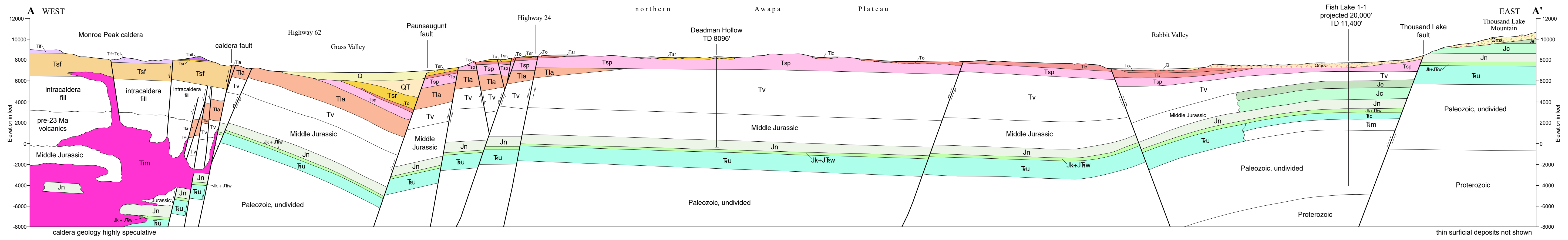
- Contact, dashed where approximately located, queried where uncertain
- Fault, unknown, dashed where approximately located, dotted where concealed
- Normal fault, dashed where approximately located, dotted where concealed; queried where uncertain; bar and ball on down-dropped side
- East flanking fault of Sevier gravity slide, concealed or eroded
- Thrust fault, dashed where approximately located, dotted where concealed, teeth on upper plate
- Reverse fault, concealed
- Gravity slide fault, dashed where approximately located, queried where uncertain; barbs on upper plate
- Lineament
- Anticline fold axis, dashed where approximately located, dotted where concealed
- Syncline fold axis, dashed where approximately located, dotted where concealed
- Monocline fold axis, dotted where concealed, arrows point to steeper limb, dashed where approximately located
- Topographic or structural wall of Monroe Peak caldera, dashed where approximately located, dotted where concealed
- Landslide scarp, dashed where approximately located
- Tensional landslide scarp
- Landslide compression ridge
- Erosional escarpment associated with periglacial nivation hollows
- Approximate limit of Last Glacial Maximum (LGM) glacial ice
- Moraine crest, symmetric
- Moraine crest, asymmetric
- Mafic dike (unit Tis)
- Igneous dike (unit Tiu)
- Clastic dike
- 5 Bedding, inclined, field measured
- Bedding, inclined, approximate, field measured
- 2 Bedding, inclined, map digitized
- 10 Bedding, inclined, photogrammetric (3-point)
- 23 Bedding, overturned, field measured
- Bedding, vertical, field measured
- Bedding, vertical, approximate, field measured
- Bedding, horizontal, field measured
- 20 Foliation, inclined, field measured
- 20 Foliation, inclined, map digitized
- Folation, vertical, map digitized
- Joint, vertical
- Striations at base of Sevier gravity slide in Dry Wash
- Sand and gravel pit
- Quarry
- Quarry, inactive
- Prospect, most not shown in Antimony Canyon
- Exploration well, plugged and abandoned (table 3)
- Adit
- Exploration trench near Pine Canyon
- Paleoseismic trench
- Sinkhole
- Volcanic vent
- Spring
- Sample location and ID-
  - A14 Radiometric age, table 1
  - G176 Geochemistry, see Biek (2020)
  - P1 Palynology, table 2
- A —— A' Line of cross section

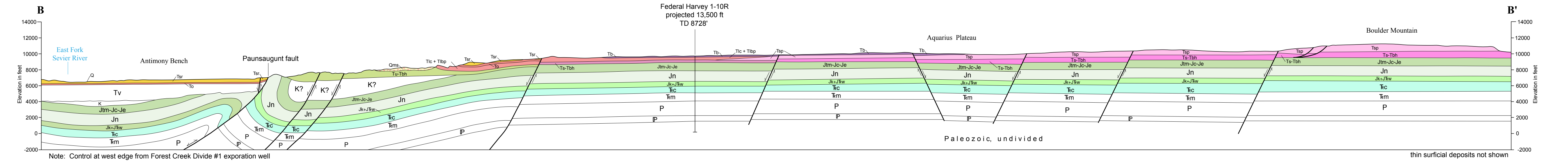
STRATIGRAPHIC COLUMN





Shaded-relief image of the Loa 30' x 60' quadrangle area; black rectangle for map area; AC = Antimony Canyon, DW = Dry Wash. Inset: BR = Basin and Range, MRM = Middle Rocky Mountains, CP = Colorado Plateau.





Note: Control at west edge from Forest Creek Divide #1 exporation well

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MAP 292DM
UTAH GEOLOGICAL SURVEY
UTAH DEPARTMENT OF NATURAL RESOURCES
2023

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Cover photo: *View south to Boulder Mountain and hummocky landslide deposits south of Bicknell Bottoms. Boulder Mountain is capped by resistant, 25.5-million-year-old volcanic rocks of Signal Peak. During the Ice Age, Boulder Mountain supported an ice cap, with glaciers that spilled off onto its flanks. The Thousand Lake fault zone, a large normal fault with about 6500 feet (2000 m) of down-to-the-west displacement, runs diagonally across the view at the base of the Carmel Formation cliffs and across the west flank of the mountain.*

Suggested citation:

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MAP 292DM
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UTAH DEPARTMENT OF NATURAL RESOURCES
2023

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CONTENTS

TABLES

GEOLOGIC MAP OF THE WEST HALF OF THE LOA 30' X 60' QUADRANGLE, GARFIELD, PIUTE, AND WAYNE COUNTIES, UTAH

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Christopher Bailey, and David W. Marchetti

MAP UNIT DESCRIPTIONS

QUATERNARY

Human-Derived Deposits

Qh **Artificial fill** (Historical) – Engineered fill and general borrow material used for major highways, Mill Meadow Reservoir dam, and small stock ponds; only larger areas of fill are mapped, but fill of variable thickness and composition should be anticipated in all developed or disturbed areas; typically less than 20 feet (6 m) thick, but fill at Mill Meadow Reservoir is about 100 feet (30 m) thick.

Qhd **Disturbed land** (Historical) – Disturbed areas (landfill, sand and gravel pits) south and southwest of Loa.

Alluvial Deposits

Qal$_1$ **Modern stream alluvium** (Holocene) − Moderately sorted sand, silt, clay, and pebble to boulder gravel deposited in active, main-stem stream channels and floodplains of Otter Creek, East Fork Sevier River, Fremont River, and Pine Creek; locally includes minor stream-terrace alluvium as much as about 10 feet (3 m) above current stream level; typically incised into older stream and fan alluvium; probably less than 20 feet (6 m) thick.

Qat, Qat$_2$, Qat$_3$, Qat$_4$, Qat$_5$, Qat$_6$

Stream-terrace alluvium (Holocene to upper Pleistocene) − Moderately sorted sand, silt, and pebble to boulder gravel that forms gently sloping terraces above, and incised by, active streams and washes; deposited in a stream-channel environment, but locally includes colluvium and small alluvial fans; subdivided only in the Bicknell and Lyman quadrangles, which were mapped in more detail at 1:24,000 scale (Biek, 2016; Biek and others, 2017); elsewhere includes several undifferentiated terrace levels (Qat) that are typically at elevations of about 10 to 20 feet (3–6 m) above active streams; subscript denotes relative age and height above adjacent drainage; Qat$_2$ ranges from about 5 to 10 feet (2–3 m), a single Qat$_3$ terrace is about 30 feet (9 m), Qat$_4$ ranges from about 30 to 50 feet (9–15 m), Qat$_5$ ranges from about 50 to 60 feet (15–18 m), and Qat$_6$ lies about 130 to 150 feet (40–45 m) above adjacent streams; typically about 15 to 50 feet (5–15 m) thick.

Qam **Alluvial marsh deposits** (Holocene to upper Pleistocene) – Not exposed but inferred to be organic-rich, moderately sorted sand, silt, and mud in small, ponded landslide basins and on Boulder Mountain; probably less than 20 feet (6 m) thick.

Qaly **Young stream alluvium** (Holocene) − Combined modern stream alluvium (Qal$_1$) and the youngest (lowest elevation) part of stream-terrace alluvium (Qat), but undivided here due to limitations of map scale; mapped along major drainages as well as in upland drainages where it may include small alluvial-fan deposits from tributary drainages and colluvium from adjacent slopes; deposits along all but the largest drainages commonly grade downslope into alluvial fans; locally includes historical debris-flow and debris-flood deposits; typically less than 20 feet (6 m) thick, but deposits in major stream valleys may locally exceed 30 feet (9 m) thick.

Qalo **Old stream alluvium** (Holocene to upper Pleistocene) – Similar to young stream alluvium (Qaly), but forms incised deposits that are of slightly higher elevation above adjacent channels; probably less than 30 feet (9 m) thick.

Qao **Old alluvial deposits** (middle to lower Pleistocene) – Moderately sorted sand, silt, and pebble to boulder gravel that forms a southward-sloping surface high above the Fremont River in the Lyman quadrangle; clasts are mostly volcanic, but include recycled chert and quartzite pebbles and small cobbles; deposited in a stream-channel environment, with largest boulders likely carried by debris flows; mapped west of Mill Meadow Reservoir where it lies about 350 feet (105 m) above modern base level; forms the southernmost of several strath terraces along the upper reaches of the Fremont River (the “Airport terrace” of Marchetti and others, 2013); Marchetti and others

(2013) reported cosmogenic ^{3}He exposure ages of 520 ± 77 ka and 735 ± 111 ka for pyroxene from two boulders of their latite of Johnson Valley (our volcanic rocks of Signal Peak) on this terrace; probably less than about 10 feet (3 m) thick, but as much as about 30 feet (9 m) thick to the north in the Forsyth Reservoir quadrangle.

Northward in the Forsyth Reservoir quadrangle, Marchetti and others (2013) showed that strath terraces are restricted to the Fremont River graben where they are cut into relatively non-resistant strata of the Sevier River Formation. The "Airport terrace," however, is cut across what they called the resistant trachyte of Lake Creek (our Trachyte lava flows of Lake Creek) and old landslide deposits (Qmsv) shed off the west flank of Thousand Lake Mountain. Possibly, the ancestral Fremont River was briefly forced out of the graben when it was filled by landslide deposits (Qmsv). Landslide deposits are exhumed from much of the graben, but remnants are present near Mill Meadow Reservoir. If this interpretation is correct, landslide deposits (Qmsv) in the Lyman quadrangle are likely early to middle Pleistocene in age.

Qaf_1 **Young fan alluvium** (Holocene) − Poorly to moderately sorted, non-stratified, clay- to boulder-size sediment containing subangular to subrounded clasts deposited principally by debris flows and debris floods at the mouths of active drainages; equivalent to the upper part of younger and middle fan alluvium (Qafy), but differentiated because Qaf_1 typically forms small, isolated fans; probably less than 30 feet (9 m) thick.

Qaf_2 **Middle fan alluvium** (Holocene to upper Pleistocene) − Similar in composition and morphology to young fan alluvium (Qaf_1), but forms inactive surfaces incised by younger stream and fan deposits; equivalent to the older, lower part of young and middle fan alluvium (Qafy); present throughout Grass Valley likely due to base-level adjustments following movement on the Paunsaugunt fault zone; larger deposits northwest and southeast of Bicknell are characterized by large, black volcanic boulders derived from Thousand Lake Mountain; probably less than 30 feet (9 m) thick.

Qafy **Young and middle fan alluvium, undivided** (Holocene to upper Pleistocene) − Poorly to moderately sorted, non-stratified, boulder- to clay-size sediment containing subangular to subrounded clasts deposited at the mouths of streams and washes; forms both active depositional surfaces (Qaf_1 equivalent) and low-level, mostly inactive surfaces incised by small streams (Qaf_2 equivalent) that are undivided here; deposited principally as debris flows and debris floods, but colluvium locally constitutes a significant part adjacent to range fronts; small, isolated deposits are typically less than a few tens of feet thick, but large, coalesced deposits in Grass Valley and Rabbit Valley are much thicker and form the upper part of basin-fill deposits; the Tanner 1-17 CO_2 test drill hole immediately west of Bicknell encountered Carmel strata at a depth of 708 feet (216 m) (Doug Sprinkel, UGS, written communication, May 14, 2015), above which is undifferentiated volcanic rocks and basin-fill alluvium, the upper part of which is this young and middle fan alluvium; Anderson and Reuter (2011) reported that unconsolidated basin fill is about 350 feet (107 m) thick in the Fish Lake 1-1 exploration drill hole northeast of Fremont, the upper part of which is this young and middle fan alluvium.

Qafo **Old fan alluvium** (upper to middle Pleistocene) – Poorly to moderately sorted, non-stratified, subangular to subrounded, boulder- to clay-size sediment with moderately developed calcic soils (caliche); forms broad, gently sloping, incised surfaces in Grass Valley, Rabbit Valley, and around Antimony Bench; deposited principally as debris flows and debris floods; fan surfaces near Bicknell are characterized by large, black volcanic boulders derived from the volcanic rocks of Signal Peak, which caps nearby Thousand Lake Mountain; typically less than a few tens of feet exposed.

The upstream part of a faulted fan surface southeast of Bicknell now lies 200 feet (60 m) above adjacent Sand Wash. Marchetti and others (2005d) reported four cosmogenic ^{3}He exposure ages of large boulders on this faulted fan surface of 83 ± 6 ka, 154 ± 8 ka, 182 ± 9 ka, and 213 ± 9 kyr, suggesting that this fan surface is at least 83 to 213 ka and was abandoned during the middle to late Pleistocene. This suggests long-term incision rates of about 1 to 2 feet per thousand years (0.3 to 0.7 m/kyr), the median of which is reasonable given rates determined elsewhere along the Fremont River (Marchetti and others, 2005d). A paleoseismic trench in a 13-foot-high (4 m) composite fault scarp there revealed two surface-faulting events with a combined throw of about 7 feet (2 m), a mean recurrence interval of 25 kyr to 42 kyr between events, and a slip rate between 0.05 and 0.02 mm/yr (Toke and others, 2018, 2021). Incision thus appears to outpace recent fault activity.

$Qafo_2$ **Older fan alluvium** (Quaternary) – Poorly to moderately sorted, non-stratified, subangular to subrounded, boulder- to clay-size sediment with calcic soils (caliche); forms isolated, boulder-covered hill at the Lyman cemetery and other small hills in nearby southern Rabbit Valley; lacks fan morphology and location of deposit in central part of the basin suggests an age older than old fan alluvium (Qafo); deposited principally as debris flows and debris floods; maximum exposed thickness about 30 feet (9 m).

Qafb **Oldest fan alluvium** (middle? to lower? Pleistocene) – Similar to old fan alluvium but much more deeply incised and preserved at higher levels on the flanks of Thousand Lake Mountain and Boulder Mountain; characterized by large, black volcanic boulders with a prominent iron-manganese patina (desert varnish), most of which are derived from the volcanic rocks of Signal Peak; locally, much of the finer-grained matrix is eroded away, leaving behind a lag of black boulders; deposited as debris flows and debris floods; no age control but amount of incision and long-term incision rates along the Fremont River suggest middle Pleistocene age; exposed thickness as much as several tens of feet.

Colluvial Deposits

Qc **Colluvium** (Holocene to upper Pleistocene) – Poorly to moderately sorted, angular to subrounded, clay- to boulder-size, locally derived sediment deposited by slope wash and soil creep on moderate slopes and in shallow depressions; locally grades downslope into deposits of mixed alluvial and colluvial origin; mapped only where it conceals contacts or mantles broad areas and shallow depressions, but is common on most slopes in the map area; typically less than 20 feet (6 m) thick.

Qco **Older colluvium** (Holocene to upper? Pleistocene) – Poorly to moderately sorted, angular to subrounded, clay- to boulder-size, locally derived sediment deposited by slope wash and soil creep on moderate slopes in Antimony Canyon where isolated, erosional colluvial remnants overlie fluvial and lacustrine strata of Antimony Canyon (Tu); probably less than 20 feet (6 m) thick.

Eolian Deposits

Qes **Eolian sand deposits** (Holocene to upper Pleistocene) – Well-sorted, fine- to medium-grained, well-rounded sand in two small deposits; in small dunes partly stabilized by vegetation south of SR-24 near where the Fremont River cuts across the Thousand Lake fault zone, the sand is quartzose and recycled principally from the Wingate Sandstone and Kayenta Formation; in a single deposit mapped west of Pollywog Lake the sand is derived from the Sevier River Formation; less than about 20 feet (6 m) thick.

Glacial Deposits

Glacial deposits are present at Boulder Mountain (Flint and Denny, 1958; Marchetti and others, 2005a, 2005b, 2007) and north of this map area on the Fish Lake Plateau (Hardy and Muessig, 1952; Osborn and Bevis, 2001; Marchetti, 2007; Marchetti and others, 2011; Willis and Doelling, 2019). During the last glacial maximum (LGM, or Pinedale advance, about 21 ka), Boulder Mountain supported an ice cap that spilled off its broad, relatively level summit in several short outlet glaciers (Marchetti and others, 2005a, 2007).

Periglacial features known as nivation hollows (see, for example, Dohrenwend, 1984) are widespread on the west-central Awapa Plateau at elevations as low as about 8350 feet (2550 m); these features are best developed on relatively non-resistant conglomeratic strata of the volcanic rocks of Langdon Mountain (Tla) where they form northwest-trending, scalloped escarpments with their eroded, steeper sides facing northeast. Thin, gravelly, silty sand deposits are present at the base of some of these escarpments but are not mapped due to limitations of scale and poor morphological expression. Nivation hollows form through repeated freeze-thaw cycles at the margins of long-lasting but slowly melting snow patches. Freeze-thaw cycles work to break and loosen rock at the margin of the snow patch, which is then washed downslope by meltwater. As the snow patch recedes in size, excavation of material continues inward, ultimately forming a scalloped slope. On the Awapa Plateau today, many nivation hollows continue to hold snow well into the summer; doubtless they held snow even later in the season during past glacial advances.

The main Pinedale advance on Boulder Mountain occurred about 23.1 ± 1.3 to 20.0 ± 1.4 ka based on ^{3}He cosmogenic exposure ages of boulders (Marchetti and others, 2005a, 2007, 2011). The Pinedale alpine glacial advance in its type area in the Wind River Range of Wyoming was about 13 to 30 ka, with glacial maxima about 16 to 23 ka on the basis of cosmogenic ^{26}Al and ^{10}Be dating (Gosse and others, 1995; Chadwick and others, 1997; Phillips and others, 1997; Pierce and others, 2018); the Pinedale is roughly coeval with the late Wisconsin glaciation, global LGM (about 26.5 to 19.0 ka; Clark and others, 2009), and Marine Oxygen Isotope Stage 2 (MIS 2, 29 to 14 ka; Lisiecki and Raymo, 2005).

Pinedale end moraines are relatively small at Boulder Mountain and glacial outwash is all but absent. The volcanic rocks of Signal Peak, which form the resistant cap of Boulder Mountain, are sculpted by glacial ice, locally forming a surface with linear ridges and grooves with local relief of several tens of feet, and roche moutonnée and polished and striated surfaces, which collectively show that ice moved radially off the plateau from one or more centers. Ice was locally at least 300 feet (90 m) thick, enough to cover Bluebell Knoll.

Older glacial deposits are not confirmed at Boulder Mountain, but they may be present on its southwest margin in the west part of the Jacobs Lake quadrangle. There, subtle yet unusual topography developed on the volcanic rocks of Signal Peak may be due to a discontinuous veneer of older glacial till. Still, this area lacks distinctive glacial landforms, and till, if present, is composed entirely of debris shed from the volcanic rocks of Signal Peak, thus making differentiation of glacial deposits and regolith problematic. Furthermore, the extent of Pinedale glacial ice on the southwest part of Boulder Mountain is uncertain and only approximately portrayed on our map; parts of this area exhibit unusual, subdued topography of low-relief hills and swales and may reflect modification by Bull Lake-age glacial ice. Proposed detailed mapping of the Jacobs Lake quadrangle by Marchetti and students will address these problems. Older glacial deposits may also be present at Miller Creek Cove in the Government Point quadrangle (see below and discussion of landslide deposits). In contrast, older glacial deposits related to the Bull Lake alpine glacial advance are present on the nearby Fish Lake Plateau (Weaver and others, 2006; Marchetti, 2007; Marchetti and others, 2011). Four cosmogenic ^{3}He exposure ages of boulders in an older Fish Lake moraine range from 79 to 159 ka with a mean age of 129 ± 39 ka and oldest ages of 152 ± 3 and 159 ± 5 ka (Marchetti and others, 2011). In their type area in the Wind River Range, Bull Lake glacial deposits are about 150 ka (Sharp and others, 2003; Pierce and others, 2011; Pierce and others, 2018), roughly coeval with the Illinoian glaciation or MIS 6 (130 to 191 ka; data from Lisiecki and Raymo, 2005; Laabs and others, 2020).

Qgr **Relict rock glaciers** (Holocene? to upper Pleistocene) – Poorly sorted, angular, cobble- to boulder-size blocks and minor fine-grained interstitial sediment that forms a rumpled, blocky surface below ledges of the volcanic rocks of Signal Peak and of the Antimony Tuff; mapped on the flanks of Boulder Mountain and southwest Awapa Plateau; characterized by a lack of vegetation and distinctive, ropy surface morphology owing to inferred flow of interstitial ice; locally includes protalus ramparts; their small size and subdued morphology, relative abundance of lichen-covered surfaces, and lack of late summer meltwater suggest these rock glaciers are dormant, now lacking interstitial ice; probably about 20 to 40 feet (6–12 m) thick.

Qgmp **Glacial till of Pinedale age** (upper Pleistocene) – Non-stratified, poorly sorted clay, silt, sand, gravel, cobbles, and boulders; clasts are matrix supported, subangular to subrounded, and derived from the volcanic rocks of Signal Peak, and, on the north part of Boulder Mountain, the Bluebell Knoll basaltic lava flow; terminal moraines are locally well developed on the west flank of Boulder Mountain and are accompanied by stagnant ice topography characterized by numerous small kettle ponds on the east side of Jacobs Valley; most end moraines are at an elevation between 9800 and 10,200 feet (2990–3110 m), although two moraines extend to about 9500 feet (2900 m) on steeper terrain; Pinedale age is based on moderately well preserved morainal topography and weak soil development, and cosmogenic ^{3}He ages of Marchetti and others (2005a, 2007); map patterns suggest thicknesses in excess of several tens of feet.

Mass-Movement Deposits

The flanks of Thousand Lake Mountain and Boulder Mountain are nearly completely covered by rotational slumps, translational landslides, and earth flows of multiple ages. Previous reconnaissance-scale geologic maps and studies of the Quaternary geology of the region (Smith and others, 1957a, 1957b, 1957c, 1963; Flint and Denny, 1958; Billingsley and others, 1987; Doelling and Kuehne, 2007), and even the in-depth studies of Marchetti and others (2005a, 2005b, 2005c, 2007), typically show only the youngest such features, those with unambiguous landslide morphology. Intervening areas of subdued but still unusual topography were interpreted as colluvium-covered, faulted bedrock blocks (Smith, 1957a, 1957b, 1957c, 1963; Marchetti, 2007), Pleistocene boulder deposits (locally over the Flagstaff Formation, which was then defined to include what we now understand to be younger tuffaceous deposits) (Smith, 1957a, 1957b, 1957c, 1963; Flint and Denny, 1958), or as volcanic boulder deposits in undifferentiated landslides, till, and colluvium (Doelling and Kuehne, 2007). Such areas of subdued but still hummocky topography are apparent when viewed in aerial imagery, and they contrast markedly from areas where this stratigraphic interval is unaffected by mass-movement processes.

The stratigraphic unit or units that contribute most of the incompetent clay-bearing debris that becomes the principal slip zone for these large landslide complexes is unclear; likely more than one unit is involved. Below their resistant volcanic caprocks, the uppermost 820 feet (245 m) or more of Boulder Mountain and the uppermost 300 feet (90 m) of Thousand Lake Mountain are concealed by mass-movement and local glacial deposits. At the north end of Thousand Lake Mountain, the stratigraphically highest exposed interval is sandstone, conglomerate, siltstone, marly siltstone, and mudstone of Eocene age, mapped as clastic rocks of Flat Top (Tc) by Doelling and Kuehne (2007), whereas the south end reveals interbedded calcarenite, crystalline limestone, conglomeratic calcarenite, intraformational conglomerate, marl, and sandstone of undetermined Eocene to Paleocene age (their carbonate and clastic rocks of Flat Top, Tcc); regional correlation of both sections is uncertain (Doelling and Kuehne, 2007). On the north flank of Boulder Mountain, the stratigraphically highest unit exposed is the Salt Wash Member of the Morrison Formation (Doelling and Kuehne, 2007), whereas Middle Jurassic Carmel Formation is the stratigraphically highest unit exposed on its south flank. However, landslide deposits on the northwest flank of Boulder Mountain locally reveal several tens of feet of white, tuffaceous and fine-grained strata similar to the Brian Head Formation as mapped on the south flank of the Marysvale volcanic field (similar, mostly coeval strata on the northeast flank of the Marysvale volcanic field are known as the Dipping Vat and possible upper Aurora Formations). We suspect that Brian Head or Dipping Vat–Aurora strata underlie the resistant caprock of Thousand Lake Mountain and Boulder Mountain. The Winsor Member of the Carmel Formation also likely provides landslide-susceptible material. Apart from a toreva block of Brian Head strata in Antimony Canyon, and fine-grained Tertiary sedimentary strata northwest of The Potholes on the northwest flank of Boulder Mountain, we did not differentiate blocks of landslide-prone strata incorporated in the landslides themselves. Such blocks are locally apparent, especially in older landslide deposits (Qmso), as, for example, in a roadcut in the SE1/4SE1/4 section 9. T. 30 S., R. 3 E., and about a mile (1.6 km) west-northwest of Government Lake near the common border of the Government Lake-Bicknell quadrangles.

Qmsh, Qms, Qms?

Landslide deposits (Historical? to upper? Pleistocene) − Very poorly sorted, locally derived material deposited by rotational and translational movement; composed of clay- to boulder-size debris as well as large, partly intact, bedrock blocks; characterized by hummocky topography, numerous internal scarps, chaotic bedding attitudes, and common small ponds, marshy depressions, and meadows; query indicates areas of unusual morphology that may be due to landsliding and Qmsh denotes small historical landslide in lower Carmel strata above Cedar Creek spring; at several locations, landslide deposits spill across the Thousand Lake fault zone and the older, less recently active parts of these deposits exhibit fault scarps (scarps that must have once been present between still existing scarps must have been destroyed by subsequent landslide movement and so the fault there is dotted); thickness highly variable, but map patterns suggest that larger deposits on the flanks of Boulder Mountain, Thousand Lake Mountain, and the southwestern Awapa Plateau exceed several hundred feet thick; undivided as to inferred age because even landslides that have subdued morphology (suggesting that they are older, weathered, and have not experienced recent, large-scale movement) 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 show that many slopes host surficial deposits that reveal evidence of creep or shallow landsliding; understanding the location, age, and stability of landslides, and of slopes that may host as-yet unrecognized landslides, requires detailed geotechnical investigations.

Marchetti and others (2007) reported three ^{3}He cosmogenic ages on boulders in the large landslide deposit at Pine Creek Cove on the west flank of Boulder Mountain that suggest the slide occurred at or before about 125 ka. The slide buries and is apparently not offset by the Thousand Lake fault, although a western splay of that fault appears to offset older landslide deposits and possibly level-2 alluvial-fan deposits in the SW1/4 section 22, T. 30 S., R. 3 E.

Marchetti and others (2007) also dated eight boulders from The Potholes and two from "Miller Creek ridges" and suggested that The Potholes formed as a debris flow between 20 and 50 ka and likely between 26 and 33 ka, and that the "Miller Creek ridges" formed as Pinedale lateral moraines about 20 ka. Flint and Denny (1958) interpreted The Potholes as older glacial drift but could not rule out a landslide origin. Following Marchetti and others (2007), we agree that The Potholes are a mass-movement feature—an earth flow composed primarily of resistant, coarse boulders and blocks of the volcanic rocks of Signal Peak. We differ, however, in re-interpreting the "Miller Creek ridges" of Marchetti and others (2007) as pressure ridges that formed as the earth flow was confined in Miller Creek Cove, not as Pinedale lateral moraines. We are perplexed as to the apparent 20 ka age of the "Miller Creek ridges"—younger than our preferred 26 to 33 ka age of The Potholes. Yet the comparatively large size of the ridges and lack of terminal or recessional moraines seems to preclude an origin as Pinedale lateral moraines. The west end of these ridges appears to be cut by the Thousand Lake fault. The Potholes exhibit subtle, discontinuous, arcuate ridges, especially along the south part, much like classic earth-flow deposits. The many small hills and intervening depressions of The Potholes may reflect the coarse nature of the deposit.

Because they lack a distinctive morphology, we map most deposits in Miller Creek Cove as mixed glacial till and landslide debris (Qgm). Flint and Denny (1958) were uncertain of this area as well and so described them as older boulder deposits of uncertain origin, whereas Marchetti and others (2005b) and Marchetti and others (2007) mapped them as Pinedale glacial till. However, small moraine pairs are present at the south side and at the head of the Cove, and a single moraine-like ridge of uncertain origin is present on the northwest side of the Cove. These small moraines are morphologically similar to Pinedale moraines on nearby Bone Flat, Dark Valley Shelf, and northeast of Jacobs Lake, which although not dated, exhibit similar morphology, extent, and elevation as the 20.0 ka Blind Lake terminal moraine in the Fish Creek drainage on the northeast flank of Boulder Mountain (Marchetti and others, 2007). We now suggest that these smaller features may be Pinedale moraines, and that the bulk of sediment in Miller Creek Cove represents older glacial deposits, likely of Bull Lake age, later subjected to earth-flow failure that produced The Potholes prior to Pinedale glaciation about 20 ka.

Qmso **Older landslide deposits** (Quaternary) – Similar to modern landslides (Qms), but morphology and position in the landscape show that they are remnants now topographically isolated from their source area; some now have such relief that they are the source of younger, modern landslides (as on Black Ridge); base of deposit on the northwest flank of Boulder Mountain locally exposes several tens of feet of white, tuffaceous and fine-grained strata similar to the Brian Head Formation as mapped on the south flank of the Marysvale volcanic field (similar, largely coeval strata on the northeast flank of the Marysvale volcanic field are known as the Dipping Vat and possible upper Aurora Formations); thickness highly variable, but deposits on Black Ridge are in excess of 400 feet (120 m) thick.

It is unclear what stratigraphic unit or units contribute most of the incompetent clay-bearing debris that becomes the principal slip zone for these large landslide complexes; likely more than one unit is involved. Below their resistant volcanic caprocks, the uppermost 820 feet (245 m) or more of Boulder Mountain and the uppermost 300 feet (90 m) of Thousand Lake Mountain are concealed by mass-movement and local glacial deposits. On the north flank of Boulder Mountain, the stratigraphically highest unit exposed is the Salt Wash Member of the Morrison Formation (Doelling and Kuehne, 2007). At the north end of Thousand Lake Mountain, the stratigraphically highest interval is sandstone, conglomerate, siltstone, marly siltstone, and mudstone of Eocene age, whereas the south end reveals interbedded calcarenite, crystalline limestone, conglomeratic calcarenite, intraformational conglomerate, marl, and sandstone of undetermined Eocene to Paleocene age; regional correlation of both sections is uncertain (Doelling and Kuehne, 2007). The Brian Head Formation, notorious for its role in landslide generation in areas to the southwest (Biek and others, 2015a), is present at the base of older landslide deposits in the southwest corner of this map area, and its mostly coeval twins the Dipping Vat and possibly upper Aurora Formations are present in fault blocks east of Bicknell, and we suspect that such beds may underlie the resistant caprock of both Thousand Lake and Boulder Mountains.

Qmso(Ts)

Older landslide blocks of Tertiary sedimentary strata (Quaternary) – Large blocks of white, tuffaceous, fine-grained strata mapped northwest of The Potholes in the Government Point quadrangle; forms the lower part of older landslides (Qmso); mapped only where not mostly covered by highly fractured blocks and rubble derived from the volcanic rocks of Signal Peak; the best exposures are in the NE1/4SE1/4 section 29, T. 30 S., R. 3 E.; as much as several tens of feet thick.

Qmsv **Landslide of Rabbit Valley** (lower? to middle? Pleistocene) – Very poorly sorted clay- to boulder-size debris and large, intact bedrock blocks deposited by rotational, translational, and earth-flow movement; characterized by large-scale hummocky topography that is more subdued than deposits mapped simply as landslides (Qms); mostly covered by boulder veneer, but individual blocks of displaced bedrock are locally mapped as Qmsv(ls), Qmsv(Je), Qmsv(Jcw), described below; interestingly, neither older Carmel strata nor Navajo Sandstone debris is present in these landslide deposits; age uncertain, but may be as young as early to middle Pleistocene (see discussion of old alluvial deposits [Qao]); thickness uncertain and highly variable, but at least locally exceeds 300 feet (90 m).

Most surfaces developed on Qmsv are covered by a lag of resistant, boulder-size blocks derived from mass wasting of the volcanic rocks of Signal Peak, which caps Thousand Lake Mountain. Elsewhere, underlying strata are locally visible beneath the boulder veneer, as, for example, at locations on the map marked by bedding attitude symbols, but given overall poor and limited exposure, it is not practical to map stratigraphic units that constitute the landslide deposits. Especially instructive exposures are in (1) Lime Kill Hollow (N1/2 section 33, T. 27 S., R. 3 E.), where tilted and faulted blocks of brecciated limestone of uncertain affinity and a clastic dike are present (we map one such "fault" east of the clastic dike and interpret it as a result of landslide movement, not later tectonic faulting), (2) to the west along the high line ditch, where folds and thrust faults are present in white, tuffaceous, mostly fine-grained, ash-rich sedimentary strata likely of the Dipping Vat Formation, and (3) in road cuts west of Tidwell Reservoir where tilted and faulted, fine-grained, ash-rich sedimentary strata and quartzite-pebble conglomerate are juxtaposed against shattered volcanic rocks of Signal Peak. High-level remnants of the landslide of Rabbit Valley are present on the footwall of the Thousand Lake fault, but most of this area is covered by still younger landslide deposits (Qms). The landslide of

Rabbit Valley forms the Rabbit Valley salient of Bartram and others (2014) and Bailey and others (2018), a massive landslide derived from the west flank of Thousand Lake Mountain.

Qmsv(Je) – Pale- to light-brown to pale-reddish-brown, fine-grained sandstone and silty sandstone mapped along Sweetwater Creek in Red Canyon, in the northeast part of the Lyman quadrangle; exposed thickness as much as about 150 feet (45 m).

Qmsv(Jcw) – Interbedded, mostly reddish-brown siltstone and fine-grained sandstone best exposed in an arroyo channel along the middle reaches of Lime Kill Hollow, north of Lyman; also poorly exposed but not mapped in adjacent hillside to north and not far to the east on the east side of a mapped clastic dike; stream-cut exposures reveal small, west-vergent recumbent folds and thrust faults; may possibly be Entrada Formation; exposed thickness as much as several tens of feet.

Qmsv(ls) – Pale-orange to yellowish-brown, fine- to medium-grained limestone that weathers to a rough surface; forms resistant, intensely fractured and locally brecciated blocks; locally overlies poorly exposed, dark-reddish-brown, pebbly, fine- to medium-grained silty sandstone and conglomerate with rounded chert and quartzite clasts (likely pre-volcanic Tertiary sedimentary strata mapped as clastic rocks of Flat Top [Tc] by Doelling and Kuehne, 2007), and white, tuffaceous mudstone, fine-grained sandstone and siltstone (possibly Dipping Vat strata); apparently lacks fossils; age and identity uncertain, and similar limestone strata are apparently not exposed on the west flank of Thousand Lake Mountain, but this limestone may be lacustrine in origin and late Eocene to early Oligocene in age and associated with early volcanism of the Marysvale volcanic field; mapped along the middle reaches of Lime Kill Hollow, north of Lyman; individual blocks are several tens of feet thick.

Qms(To)

Landslide blocks of Osiris Tuff (Quaternary) – Large, mostly intact, rotated blocks of Osiris Tuff (To) mapped on the northwest flank of the Escalante Mountains in the southwest corner of the map area; the degree of displacement due to landsliding versus offset by strands of the Paunsaugunt fault zone is uncertain.

Qms(Tla)

Landslide blocks of volcanic rocks of Langdon Mountain (Quaternary) – Large, mostly intact, rotated blocks of the volcanic rocks of Langdon Mountain (Tla) mapped east of Otter Creek Reservoir.

Qms(Tlc)

Landslide blocks of trachyte lava flows of Lake Creek (Quaternary) – Large, mostly intact, little rotated blocks of the trachyte lava flows of Lake Creek mapped on the northwest flank of the Escalante Mountains in the southwest corner of the map area, where the degree of displacement due to landsliding versus offset by strands of the Paunsaugunt fault zone is uncertain; also mapped in Dry Wash where it is juxtaposed against Tertiary sedimentary strata, upper unit (Tsu).

Qms$_1$(Tsp)

Landslide blocks of volcanic rocks of Signal Peak (Holocene to middle? Quaternary) – Large, mostly intact, little-rotated blocks of the volcanic rocks of Signal Peak (Tsp) on the west flank of Boulder Mountain; appear to reflect incipient failure of the west edge of the plateau; slip surfaces likely sole into fine-grained, ash-rich sedimentary deposits that underlie the volcanic rocks of Signal Peak, or into non-resistant Jurassic strata.

Qms$_2$(Tsp)

Highly fractured landslide blocks of volcanic rocks of Signal Peak (Quaternary) – Large, highly fractured, rotated blocks of the volcanic rocks of Signal Peak (Tsp) on the western flank of Boulder Mountain; appear to reflect progressive failure of the west edge of the plateau; slip surfaces likely sole into fine-grained, ash-rich sedimentary deposits that underlie the volcanic rocks of Signal Peak, or into non-resistant Jurassic strata.

Qms(Tbh)

Landslide block of Brian Head Formation (Quaternary) – Large, rotated block of the Brian Head Formation (Tbh) mapped in Antimony Canyon; see unit Tbh description.

Qmt **Talus** (Holocene to upper Pleistocene) – Poorly sorted, angular cobbles and boulders and finer-grained interstitial sediment deposited principally by rockfall on or at the base of steep slopes; talus that is part of large landslide complexes is not mapped separately; talus is common at the base of steep slopes across the map area, but is mapped only where it conceals contacts or forms broad aprons below cliffs of resistant bedrock units; commonly grades downslope into colluvium; typically less than 30 feet (9 m) thick.

Mixed-Environment Deposits

Qac	**Alluvium and colluvium** (Holocene to upper Pleistocene) − Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment deposited in swales and small drainages by fluvial, slope-wash, and creep processes; generally less than 20 feet (6 m) thick.
Qaco	**Older alluvium and colluvium** (upper? Pleistocene) − Similar to mixed alluvium and colluvium (Qac), but forms incised, isolated remnants, typically along the upper reaches of streams; probably about 20 to 30 feet (6–9 m) thick.
Qafc	**Fan alluvium and colluvium** (Holocene to upper? Pleistocene) − Poorly to moderately sorted, nonstratified, clay- to boulder-size sediment deposited principally by debris flows, debris floods, and slope wash at the mouths of active drainages and the base of steep slopes; locally reworked by small, ephemeral streams; forms coalesced apron of fan alluvium and colluvium impractical to map separately at this scale; includes fan alluvium along the margins of Grass Valley that exhibits a steeper slope than the larger, coalesced fan deposits that emanate from major drainages; typically 10 to 40 feet (3–12 m) thick.
Qafco	**Older fan alluvium and colluvium** (upper? Pleistocene) − Similar to mixed fan alluvium and colluvium (Qafc), but forms incised, isolated remnants, typically along the upper reaches of streams; probably about 20 to 30 feet (6–9 m) thick.
Qae	**Alluvium and eolian sand** (Holocene to upper Pleistocene) − Moderately sorted gravel, sand, and silt deposited in small channels and on alluvial flats, and well-sorted, fine- to medium-grained, reddish-brown eolian sand locally reworked by alluvial processes; mapped principally in shallow depressions on the Navajo Sandstone; as much as about 20 feet (6 m) thick.
Qaeo	**Older alluvium and eolian sand** (upper? Pleistocene) – Similar to younger alluvium and eolian sand deposits, but forms incised, inactive surfaces; mapped south of SR-24 at the east edge of the quadrangle where it is as much as about 20 feet (6 m) thick.
Qea	**Eolian sand and alluvium** (Holocene to upper? Pleistocene) − Well-sorted, fine- to medium-grained, reddish-brown eolian sand locally reworked by alluvial processes, and poorly to moderately sorted gravel, sand, and silt deposited in small channels; as much as about 20 feet (6 m) thick.
Qgm	**Glacial till and mass movement deposits, undivided** (Holocene to Pleistocene) – Mapped in Miller Creek Cove where deposits lack distinctive morphology; see landslide map unit description for explanation.
Qlc	**Lacustrine and colluvial deposits** (Holocene to Pliocene?) – Not exposed but presumed to be silt and clay that interfingers with colluvium near the basin margins; forms the flat, periodically inundated floors of Dry Lake, Hay Lakes, Lost Lake, and other small basins on the Aquarius Plateau, each of which fills shallow, closed depressions on basaltic lava flows or the volcanic rocks of Signal Peak; probably less than about 15 feet (5 m) thick, but Dry Lake deposits may be somewhat thicker.
Qla	**Lacustrine and alluvial deposits** (Holocene to upper Pleistocene) – Silt and clay that interfingers with colluvium near the basin margins; partly fills small, ice-scoured depressions on top of Boulder Mountain, which are commonly littered with boulders of the volcanic rocks of Signal Peak; also used for fine-grained deposits of landslide-related sag ponds on the flanks of Boulder Mountain.
Qmc	**Landslides and colluvium** (Holocene to upper Pleistocene) − Unsorted, locally derived, clay- to boulder-sized material and large, displaced bedrock blocks; mapped where landslide deposits are difficult to identify and intermixed with colluvium; the large deposit north of Cedar Creek in the Lyman quadrangle is locally in excess of 100 feet (30 m) thick, but most deposits are less than several tens of feet thick.
Qmtc	**Talus and colluvium** (Holocene to upper Pleistocene) – Poorly sorted, angular to subangular, cobble- to boulder-size and finer-grained interstitial sediment deposited principally by rockfall and slope wash on steep slopes throughout the quadrangle; includes minor alluvial sediment at the bottom of washes; talus and colluvium are common on steep slopes across the map area, but are mapped only where they conceal contacts or form broad aprons below cliffs of resistant bedrock units; commonly grades downslope into colluvium; generally less than 30 feet (9 m) thick.
Qmtco	**Older talus and colluvium** (upper? Pleistocene) – Similar to talus and colluvium but forms incised surfaces no longer receiving sediment, capped by resistant blocks of Wingate Sandstone, now isolated from nearby Wingate cliffs; generally less than 30 feet (9 m) thick.

Residual Deposits

Qr **Residual deposits** (Holocene to upper? Pleistocene) – Relict blocks of Osiris Tuff that form a resistant cap on the Volcanic Rocks of Langdon Mountain above Antimony Creek, about 2 miles (3 km) west of Pollywog Lake; Osiris blocks are as much as about 15 feet (5 m) in diameter.

Stacked-Unit Deposits

Stacked-unit deposits consist of a veneer of Quaternary deposits that mostly conceal underlying bedrock units. Although most bedrock in the quadrangle is partly covered by colluvium or other surficial deposits, we use stacked units to indicate areas where bedrock is mostly obscured by thin surficial deposits derived from upslope sources rather than just residual weathering of underlying bedrock. Many of these units were only used in the more detailed maps of the Bicknell and Lyman quadrangles and thus are not consistently applied across this map.

Qc/To **Colluvium over Osiris Tuff** (Holocene to upper Pleistocene/lower Miocene to upper Oligocene) – Mapped in Parker Hollow and northeast of Black Ridge where colluvium and locally minor alluvium mostly conceal Osiris Tuff.

Qc/Tsp **Colluvium over volcanic rocks of Signal Peak** (Holocene to upper Pleistocene/upper Oligocene) – Mapped in the northwest corner of the Bicknell quadrangle where a veneer of colluvium mostly conceals volcanic rocks of Signal Peak.

Qac/Tsp

Mixed alluvium and colluvium over volcanic rocks of Signal Peak (Holocene/upper Oligocene) – Mapped west of Loa where an apron of alluvium, fan alluvium, and colluvium mostly conceals volcanic rocks of Signal Peak.

Qgmp/Tsp

Glacial till of Pinedale age over volcanic rocks of Signal Peak (upper Pleistocene/upper Oligocene) – Mapped on Boulder Mountain where a sparse and discontinuous veneer of glacial till overlies ice-sculpted bedrock; the volcanic rocks of Signal Peak, which form the resistant caprock of Boulder Mountain, are characterized by a rugged, pitted surface with several tens of feet of local relief, and roche moutonnée, ice-sculpted elongate ridges, and polished and striated surfaces; a lag of boulders derived from the volcanic rocks of Signal Peak, and locally from basaltic lava flows of Bluebell Knoll, litter the plateau's surface; surficial deposits are only locally as much as a few tens of feet thick.

Qgmp/QTls

Glacial till of Pinedale age over limestone (upper Pleistocene/Pleistocene? to Pliocene?) – Mapped in the Government Point quadrangle where a sparse and discontinuous veneer of glacial till, commonly as a lag of boulders derived from the volcanic rocks of Signal Peak and basaltic lava flows of Bluebell Knoll, overlies ice-sculpted ridges eroded into carbonate deposits of uncertain origin; surficial veneer is typically less than 3 feet (1 m) thick.

Carbonate deposits are white-weathering, medium-gray, impure, fine-grained limestone that forms poor exposures but that is likely thin to thick bedded and as much as about 25 feet (8 m) thick. Darker gray algal laminations and lighter gray pisolites are locally common. Subangular to subrounded silt to coarse sand typically composes less than about 10% of the rock and is dominantly quartz, plagioclase, and minor pyroxene phenocrysts likely recycled from underlying volcanic rocks of Signal Peak. The carbonate unconformably overlies volcanic rocks of Signal Peak, but its relationship to the 3.4 Ma basaltic lava flows of Bluebell Knoll is concealed by glacial till and thus uncertain. The carbonate may reflect ponding and inundation of a Bluebell Knoll-age paleodrainage. No other outcrops of the carbonate unit are known on Boulder Mountain or in the surrounding area.

Qgmp/Tbbl

Glacial till of Pinedale age over basaltic lava flows of Bluebell Knoll (upper Pleistocene/ Pliocene?) – Mapped in the Government Point quadrangle where the Bluebell Knoll basaltic lava flows are overlain by a sparse and discontinuous veneer of glacial till or a lag of boulders derived from the volcanic rocks of Signal Peak; surficial deposits are only locally as much as about 10 feet (3 m) thick.

Qgmp/Tbblc

Glacial till of Pinedale age over basaltic cinders of Bluebell Knoll (upper Pleistocene/ Pliocene?) – Mapped in the Government Point quadrangle where the deeply eroded vent of the Bluebell Knoll basaltic lava flows is overlain by a sparse and discontinuous lag of boulders derived from the volcanic rocks of Signal Peak; surficial deposits are less than 3 feet (1 m) thick.

QUATERNARY and TERTIARY

QTms(Tsdb)

Older landslide deposits of Tertiary sedimentary strata, Dipping Vat Formation, and Three Creeks Tuff Member of Bullion Canyon Volcanics (Quaternary? to Pliocene?/Oligocene to Eocene?) – Forms steep, rugged hills north of Bicknell, in the hanging wall of the Thousand Lake fault zone, that are mostly covered by volcanic boulders derived from the volcanic rocks of Signal Peak; limited exposures reveal fine-grained, ash-rich sedimentary strata, conglomerate with pebble- and cobble-size volcanic clasts, and sedimentary strata that lack volcanic materials, all of which occur in blocks of widely varying attitudes and that may be fault-bounded bedrock blocks or rotated blocks that are part of a deeply eroded landslide; Bailey and others (2018) reported ^{3}He cosmogenic exposure ages of 400 to 500 ka on boulders of latite of Johnson Valley (our volcanic rocks of Signal Peak) below Yellow Ledges and interpreted this as a minimum age for the deposit, which they included with the much younger landslide of Rabbit Valley (Qmsv); the distribution and thickness of individual bedrock units is highly variable, but map patterns suggest that the combined package is in excess of 900 feet (275 m) thick.

Fine-grained, ash-rich facies, locally well exposed between Bicknell and Crescent Canyon, are mostly light-gray to white, thin- to medium-bedded, fine- to medium-grained, locally coarse-grained sandstone, siltstone, and mudstone, here assigned to the Dipping Vat Formation, a term McGookey (1960) applied to similar strata widely exposed on the northeast flank of the Marysvale volcanic field. These beds yielded three teeth of *Saltirius utahensis* (stingray) only known from the coeval variegated unit of the Brian Head Formation exposed on the south flank of the volcanic field; they also yielded the charophytes *Harrisichara tuberculate*, *Sphaerochara aff. Major*, and *Hornichara* also reported from the Brian Head Formation. Coarse-grained facies are pebble-to-boulder sandstone and conglomerate of possible Sevier River Formation affinity (or possibly of the older Bullion Canyon Volcanics).

North of Sand Wash in the Bicknell quadrangle, at the bedding attitude symbol showing a dip of 50 to 75 degrees north, reddish-brown mudstone, yellowish-brown sandy and micritic limestone, quartzite- and chert-pebble conglomerate, and medium- to coarse-grained "salt and pepper" sandstone compose a block of non-volcaniclastic strata, collectively a few tens of feet thick, of uncertain age and correlation; these same beds (Ts) are poorly exposed south of Sand Wash. These strata appear similar to strata in Lime Kill Hollow, about 2 miles (3 km) north of Lyman, and to middle Eocene (Duchesnean Land Mammal Age, about 42–38 Ma) clastic strata of Flat Top (map unit Tc of Doelling and Kuehne, 2007). They are also in a similar stratigraphic position as the Crazy Hollow Formation and the formation of Aurora (see Willis, 1988) on the northeast flank of the Marysvale volcanic field, and as the informally named variegated unit of the Brian Head Formation and underlying conglomerate at Boat Mesa (see Biek and others, 2015a) on the southeast flank of the volcanic field.

QTms/Jc

Older landslide deposits over Carmel Formation (Quaternary to Pliocene/Middle Jurassic) – Mapped along the Thousand Lake fault zone northeast of Bicknell where Carmel (and locally Kayenta) strata are mostly concealed by older landslide deposits.

TERTIARY

Upper Tertiary Basaltic Lava Flows

In southwest Utah, including within the Marysvale volcanic field, basaltic rocks are synchronous with basin-range extension and thus with initial development of modern topography that began in southwest Utah between 23 and 17 million years ago; they are part of mostly small, bimodal (basalt and high-silica rhyolite) eruptive centers (Christiansen and Lipman, 1972; Rowley and Dixon, 2001). Few of these relatively small-volume, widely scattered, basaltic lava flows in the Loa 30' x 60' quadrangle are dated (table 1), but all appear to be of Pliocene to middle Miocene age. Farther southwest, in the Panguitch 30' x 60' quadrangle, dozens of younger basaltic lava flows are as young as latest Pleistocene or possibly early Holocene (Biek and others, 2015a).

The following descriptions of individual basaltic lava flows are brief because of widespread petrographic and geochemical similarity among flows, because of their typically poorly exposed and deeply weathered outcrops, and because of limited geochemical and age data; we do not differentiate many flows in the south-central part of the map area for these reasons and because of poor exposure and poor geomorphic expression between vent areas. Except where noted, all lava flows are dark gray and fine grained and contain small olivine phenocrysts (commonly altered to iddingsite) and abundant small plagioclase and clinopyroxene phenocrysts. Basaltic lava flows typically have a rubbly base and a dense, jointed middle part; the vesicular upper part of the lava flows is typically eroded away. Cinder cones are deeply eroded and many vent areas lack appreciable cinder deposits. Lava flows are typically 20 to 30 feet (6–9 m) thick and commonly consist of multiple thin sheets separated by thin rubbly zones. Where it fills paleotopography, a single flow can exceed 200 feet (60 m) thick.

Basaltic magmas are partial melts derived from the compositionally heterogeneous lithospheric mantle, which, coupled with fractional crystallization, may account for most of the geochemical variability between individual lava flows (Lowder, 1973; Best and Brimhall, 1974; Mattox, 1991; Nelson and Tingey, 1997; Johnson and others, 2010). Nb/La ratios for virtually all samples of basaltic and andesitic lava flows from the map area are less than 1.0, suggesting a lithospheric mantle source (Fitton and others, 1991). Rock names follow LeBas and others (1986) and are based on limited geochemistry; virtually all flows are classified as basalt, potassic trachybasalt, or less commonly basaltic trachyandesite. See Table 4 for major- and trace-element data for volcanic rocks in the west half of the Loa 30' x 60' quadrangle. Map units are listed alphabetically below.

Tb **Basaltic lava flows, undivided** (Pliocene to Miocene) – Used where distinguishing between basaltic lava flows is unclear due to lack of distinctive morphology and inadequate geochemical and age data; also used for basaltic lava flow near Browns Canyon southwest of Greenwich; includes a large complex of basaltic lava flows that erupted from vents near Butterfly Lake, and at Spring Knoll, Pelham Knoll, and other unnamed vents on the Aquarius Plateau.

Tba **Basaltic andesite lava flow** (Miocene) – Basaltic andesite or basaltic lava flows in the northwest corner of the map area; may be a late extrusive phase of igneous rocks related to the Monroe Peak caldera or may represent early basaltic volcanism associated with early basin-range extension; maximum thickness about 100 feet (30 m).

Tbak **Basaltic lava flows of Abes Knoll** (Pliocene to Miocene) – Basalt to potassic trachybasalt that may have erupted from the Abes Knoll area near the northwest margin of the Awapa Plateau; overlies and is overlain by gravels of the Sevier River Formation; maximum exposed thickness is about 140 feet (40 m).

Tban **Basaltic lava flows of Antimony** (Pliocene to Miocene) – Basalt to potassic trachybasalt exposed west of the Paunsaugunt fault zone southeast of Otter Creek Reservoir; vent unknown, but thickness patterns suggest that it flowed westward and may have erupted from a concealed or eroded vent at or near the Paunsaugunt fault zone; Best and others (1980) reported K-Ar ages of 5.0 ± 0.3 and 5.4 ± 0.4 Ma for this flow; flow thins westward from the fault zone where it is as much as about 400 feet (120 m) thick.

Tbbak **Basaltic lava flows of Bald Knoll** (Pliocene to Miocene) – Potassic trachybasalt to shoshonite that erupted from a vent at Bald Knoll, one of several vents aligned along a northwest trend on the central Awapa Plateau; forms poorly exposed sage-covered surface of apparent similar age to the nearby Cedar Peak and Flossie Knoll flows.

Tbbp **Basaltic lava flows of Big Point** (Pliocene to Miocene) – Basalt that erupted from Big Point at the southwest margin of the Awapa Plateau; overlies unmapped gravels of the Sevier River Formation along the south-facing escarpment of Big Point where it is as much as 120 feet (35 m) thick.

Tbbk **Basaltic lava flows of Burnt Knoll** (Pliocene to Miocene) – Basalt that erupted from a vent at Burnt Knoll on the central Awapa Plateau; forms poorly exposed sage-covered surface of apparent similar age to the nearby Bald Knoll, Cedar Peak, and Flossie Knoll flows.

Tbbl **Basaltic lava flows of Bluebell Knoll** (Pliocene) – Basalt that erupted from a vent at Bluebell Knoll on Boulder Mountain; yielded an ^{40}Ar/^{39}Ar age of 3.38 ± 0.19 Ma (table 1; UGS & NMGRL, 2009).

Tbbu **Basaltic lava flows of The Buttes** (Pliocene to Miocene) – Basalt that erupted from the North, Middle, and South Buttes, which are aligned north-to-south near the head of Dry Wash at the west edge of the Awapa Plateau; forms poorly exposed sage-covered surface of apparent similar age to nearby basaltic lava flows; query indicates uncertain designation.

Tbcp **Basaltic lava flows of Cedar Peak** (Pliocene to Miocene) – Shoshonite that erupted from a vent at Cedar Peak, one of several vents aligned along a northwest trend on the central Awapa Plateau; forms poorly exposed sage-covered surface of apparent similar age to the nearby Bald Knoll and Flossie Knoll flows.

Tben **Basaltic lava flows of Elsies Nipple** (Pliocene) – Basalt that erupted from a vent at Elsies Nipple about 5 miles (8 km) southwest of Loa; Mattox (2001) reported a K-Ar age of 6.9 ± 0.3 Ma on a sample from Elsies Nipple, and our sample B100913-6 yielded an ^{40}Ar/^{39}Ar plateau age of 4.87 ± 0.02 Ma (table 1); flowed eastward down the dip slope of the Awapa Plateau, showing that the eastward tilt of the plateau was established by earliest Pliocene time; maximum thickness about 270 feet (80 m) (Mattox, 2001).

Tbfl **Basaltic lava flows of Fish Lake** (Pliocene to Miocene) – Potassic trachybasalt to shoshonite that probably erupted from an unknown vent in the

Burrville quadrangle north of this map area, possibly at a small broad hill at 431035 E, 4262484 N (UTM zone 12S, NAD83) that has poorly exposed scoria (Willis and Doelling, 2019); distinction of this flow from the lithologically similar Abes Knoll flow near SR-24 is poorly defined; locally covered by gravels here assigned to the Sevier River Formation; maximum exposed thickness is about 30 feet (9 m).

Tbfk **Basaltic lava flows of Flossie Knoll** (Pliocene to Miocene) – Basalt that erupted from a vent at Flossie Knoll, one of several vents aligned along a northwest trend on the central Awapa Plateau; forms poorly exposed sage-covered surface of apparent similar age to the nearby Cedar Peak and Bald Knoll flows.

Tbif **Basaltic lava flows of Indian Flat** (Miocene) – Basalt to hawaiite exposed near the southeast margin of the Monroe Peak caldera that overlies the Sevier River Formation; sample G100913-3 yielded an ^{40}Ar/^{39}Ar isochron age of 14.08 ± 0.16 Ma (table 1).

Tbl **Basaltic lava flows of Loa** (Pliocene to Miocene) – Scattered outcrops of shoshonite north and west of Loa; vent area unknown; maximum exposed thickness is about 20 feet (6 m).

Tblslk **Basaltic lava flows of Lost Spring Knoll and Lost Knoll** (Pliocene?) – Basaltic lava flows that likely erupted from deeply eroded vents at Lost Spring Knoll and Lost Knoll; may include basaltic flows derived from a separate vent inferred by Williams and Hackman (1971) at or near the southern quadrangle boundary west of Coyote Hollow Reservoir.

Tbnp **Basaltic lava flows of Nicks Point** (Pliocene to Miocene) – Basalt to shoshonite that may have erupted from a vent near the head of Dry Wash, near the southwest margin of the Awapa Plateau; Best and others (1980) reported a K-Ar age of 6.5 ± 0.3 Ma for the flow (table 1); as much as about 120 feet (35 m) thick in excellent exposures at the west edge of the plateau.

Tbpk **Basaltic lava flows of Parker Knoll** (Pliocene to Miocene) – Basalt to potassic trachybasalt erupted from vent at Parker Knoll at the west edge of the central Awapa Plateau; forms poorly exposed tree- and sage-covered surface of apparent similar age to the nearby Buttes lava flows.

Tbpp, Tbpp?

Basaltic lava flows of Pine Peaks (Pliocene to Miocene) – Remnant lava flow near Pine Peaks at the west edge of the Awapa Plateau; a single sample is of latite composition; query indicates uncertain correlation west of the Paunsaugunt fault zone; as much as about 100 feet (30 m) thick.

Tbpl **Basaltic lava flows of Pollywog Lake** (Pliocene to Miocene) – Basalt to potassic trachybasalt likely erupted from vent northwest of Pollywog Lake; forms poorly exposed sage-covered surface of apparent similar age to the nearby basaltic lava flows on the southern Awapa Plateau.

Tbrk **Basaltic lava flows of Red Knoll** (Pliocene to Miocene) – Potassic trachybasalt erupted from vent at Red Knoll on the central Awapa Plateau; forms poorly exposed sage-covered surface of apparent similar age to other nearby basaltic lava flows on the southern Awapa Plateau.

Tbsk **Basaltic lava flows of Smooth Knoll** (Pliocene to Miocene) – Basalt to potassic trachybasalt erupted from vent at Smooth Knoll on the southern Awapa Plateau; forms a poorly exposed sage-covered surface of basaltic lava flows of apparently similar age.

Tbtk **Basaltic lava flows of Timbered Knoll** (Pliocene to Miocene) – Basalt erupted from vent at Timbered Knoll on the southern Awapa Plateau; forms poorly exposed sage-covered surface of apparent similar age to other nearby basaltic lava flows.

Tertiary Volcanic and Volcaniclastic Strata

Tis **Mafic dike** (Miocene) – Medium- to dark-gray mafic dike of probable basaltic composition; contains phenocrysts of olivine, altered to iddingsite, in a fine-grained groundmass; deeply weathered and mostly nonresistant; intrudes Carmel strata southwest of Black Ridge and is roughly parallel to the Thousand Lake fault zone; typically 1 to 6 feet (0.3–2 m) wide.

Tsr, Tsr?, Tsrb

Sevier River Formation (Miocene) – Moderately to poorly consolidated, light-gray and grayish-brown conglomerate, pebbly sandstone, sandstone, and minor siltstone; locally contains interbedded basaltic lava flows, most of which are mapped separately as Tsrb; pebble- to boulder-size clasts are subrounded to rounded intermediate-composition volcanic rocks, including, locally, clasts of Osiris Tuff; locally contains thin, white, air-fall ash beds, some of which may belong to the Joe Lott Tuff Member of the Mount Belknap Volcanics (Rowley and others, 1986a); forms poorly exposed, planar and gently sloping, sagebrush-covered surfaces on the Awapa

Plateau where it unconformably overlies the Osiris Tuff and older map units; on the Sevier Plateau in the west-central part of the Greenwich quadrangle, map unit is lithologically similar to, but unconformably overlies, upper moat sediments (Tum; along the inside southern edge of the Monroe Peak caldera); the Sevier River Formation is similar to sedimentary rocks within the volcanic rocks of Langdon Mountain, but can be distinguished by stratigraphic position (above the Osiris Tuff) and the local presence of subrounded clasts of Osiris Tuff and olivine basalt; query indicates small, poor exposures near the head of Antimony Canyon south of Dry Lake that may be older mixed alluvium and colluvium, and near Pine Peaks near the west margin of the Awapa Plateau that may be volcanic rocks of Langdon Mountain; at least 500 feet (150 m) thick in the Beaver 30' x 60' quadrangle to the west (Rowley and others, 2005), as much as 600 feet (180 m) thick in the Burrville quadrangle immediately north of this map area (Willis and Doelling, 2019), and as much as about 450 feet (140 m) thick on the Awapa Plateau.

The Sevier River Formation was named by Callaghan (1938) for partly consolidated basin-fill deposits near Sevier, Utah, on the north side of the Marysvale volcanic field. The name was formerly applied to all basin-fill deposits in and near Sevier and Grass Valleys, but, because most of its exposures are in adjacent ranges, it was later recognized to have been deposited in basins that formed generally prior to the main episode of basin-range extension, which created the present topography (Rowley and others, 1981b, 1998, 2002; Rowley, 1998). In and near its type area near the town of Sevier, the Sevier River Formation contains air-fall tuffs and basaltic lava flows with numerous fission-track and K-Ar ages between about 14 and 6 Ma (Steven and others, 1979; Best and others, 1980; Rowley and others, 1994); Willis (1988) reported a fission-track age of 5.2 ± 0.4 Ma on a reworked ash bed in the upper part of the formation in the Aurora quadrangle to the north. The age of the Sevier River Formation is poorly constrained on the Awapa Plateau, but at the plateau's west margin it concordantly overlies the 23 Ma Osiris Tuff and is locally overlain by 5.0 to 6.5 Ma basaltic lava flows in the Antimony and upper Dry Wash areas. We obtained a detrital zircon maximum depositional age of about 20 Ma for our sample A030218-1 near the base of the formation at the north end of Black Canyon where it contains sparse, rounded cobbles of Osiris Tuff (GeoSep Services and Utah Geological Survey, 2019). The Sevier River Formation thus spans much of the Miocene and was deposited in basins of different ages that bear no relationship to the modern topography across this part of south-central Utah. The monoclinal westward tilt of Sevier River strata and underlying Osiris Tuff along the northeast margin of Grass Valley may be related to gravity-driven "withdrawal" of weak Jurassic Arapien Formation and overlying units from beneath the high plateaus as proposed by Cline and Bartley (2007).

Tsrb **Basaltic lava flows in the Sevier River Formation** (Miocene) – Dark-gray, fine-grained basaltic lava flows interbedded in gravels of the Sevier River Formation; contain small olivine phenocrysts (commonly altered to iddingsite) and common small plagioclase and clinopyroxene phenocrysts; typically 10 to 30 feet (6–9 m) thick, forming resistant ledges within non-resistant gravels; west of Greenwich on the Sevier Plateau, underlies the 14 Ma basaltic lava flows of Indian Flat (Tbif).

Tum **Upper moat sediments** (lower Miocene) – Mostly unconsolidated, light-brown and gray sandstone, mudflow breccia, and conglomerate; includes a white ash-fall tuff bed as much as 9 feet (3 m) thick; a moat is created between the caldera wall and the caldera interior, the latter of which has been uplifted by emplacement of the resurgent pluton (Tim); sediments were derived from erosion of the Monroe Peak caldera wall and of the caldera interior, deposited mostly by fluvial and debris-flow processes within about 0.6 mile (1 km) of the wall; unit overlies volcanic rocks of Sage Flat (Tsf) and thus was deposited in the moat after resurgent magmas (Tim) were intruded; similar sediments, intertongued and mapped with volcanic rocks of Sage Flat, were deposited near the caldera wall before, during, or after resurgent doming; later, sediments of the Sevier River Formation (Tsr) were also deposited in the moat, unconformably on the upper moat sediments; unit contains blocks of outflow facies of Osiris Tuff (To) as much as 15 feet (5 m) across, as well as blocks of other volcanic units, all of which were derived from the topographic wall of the caldera, as described by Rowley and others (1986a); about 330 feet (100 m) thick where mapped separately, but thicker where mapped with volcanic rocks of Sage Flat.

Tdl **Dacite of Lower Box Creek Reservoir** (lower Miocene) – Resistant, gray, light-brown, and pinkish- and greenish-gray, flow-foliated, dacitic lava flows or possibly a low volcanic dome; base typically consists of black vitrophyre as much as 15 feet (5 m) thick that locally overlies light-greenish-gray lava flow and flow breccias each as much as 9 feet (3 m) thick; contains abundant, commonly large (as much as 0.8 inch [2 cm]) phenocrysts of sanidine, subordinate plagioclase, pyroxene, and biotite, and minor Fe-Ti oxides, hornblende, and olivine; a late intracaldera unit that is the extrusive equivalent of a stock or plug related to, but slightly younger than, the resurgent intrusive rocks of Monroe Peak caldera (Tim), as noted by Rowley and others (1986a); yielded an ^{40}Ar/^{39}Ar isochron age on sanidine of 22.48 ± 0.04 Ma (L.W. Snee, unpublished data); maximum thickness about 200 feet (60 m).

Tim **Intrusive rocks of the Monroe Peak caldera** (lower Miocene to upper Oligocene) – Moderately resistant, light-gray and grayish-brown monzonite porphyry with phenocrysts of plagioclase, generally subordinate potassium feldspar, and minor pyroxene, biotite, and Fe-Ti oxides; lithologically and petrographically similar to the Osiris Tuff except that the unit contains fewer phenocrysts and coarser groundmass; appear to be older than the volcanic rocks of Sage Flat (Tsf), which are unaltered and lack quartz masses; considered to be part of a composite resurgent intracaldera pluton that intruded extrusive rocks (primarily intracaldera Osiris Tuff) of the Monroe Peak caldera, as described by Steven and others (1984) and Rowley and others (1986a); one part of the composite pluton yielded a fission-track age on zircon of 21.5 ± 0.8 Ma from a sample collected about 7 miles (12 km) west-northwest of the northwest map boundary (Rowley and others, 1986a, 1988b), and we report an ^{40}Ar/^{39}Ar isochron age on sanidine of 23.11 ± 0.09 Ma from our sample G100913-7 in the northwest corner of the Greenwich quadrangle; another intracaldera pluton related to Tim, but litholgically distinctive, is the Central Intrusion, which is the main host for uranium deposits in the central mining area at Marysvale (Rowley and others, 1988a, 1988b); exposed thickness is as much as about 600 feet (180 m).

Tif, Tifh

Lava flows of Indian Flat (lower Miocene) – Resistant, reddish-brown, gray, and pinkish- and greenish-gray, commonly flow-foliated, andesitic, dacitic, and rhyodacitic lava flows; includes lava flows of Greenwich Creek mapped by Rowley and others (1986a) in the northwest corner of the Greenwich quadrangle, which are in part older than the volcanic rocks of Sage Flat; may include volcanic domes; unit consists of numerous lithologically similar flows containing sparse to moderately abundant phenocrysts of plagioclase, sanidine, pyroxene, biotite, Fe-Ti oxides, and minor olivine in a glassy to partly devitrified groundmass; some flows contain abundant, greenish-gray to gray, pebble-size volcanic and plutonic inclusions; a late intracaldera unit that is the extrusive equivalent of a stock or plug related to the resurgent intrusive rocks of Monroe Peak caldera (Tim); unit is thin immediately east and south of Lower Box Creek reservoir, but thickens considerably to the east, where it apparently pooled against the eastern topographic wall of the caldera; source of lava flows probably was located along the Box Creek fault; letter "h" indicates areas that are hydrothermally altered, silicified, and possibly mineralized as mapped by Rowley and others (1986a); maximum exposed thickness is about 650 feet (200 m) where it pooled against the inside of the caldera topographic wall, but it pinches out southward.

Tsf, Tsfh

Volcanic rocks of Sage Flat (lower Miocene) – Resistant, gray, reddish-brown, black, and purplish-brown andesitic lava flows and subordinate volcanic mudflow breccia and sandstone and conglomerate with volcanic clasts; these mostly clastic strata, including landslide breccia, thicken towards the caldera wall; lava flows are locally petrographically similar to those of Indian Flat (Tif); a late intracaldera unit that is another extrusive equivalent of a stock or plug related to the resurgent intrusive rocks of Monroe Peak caldera (Tim); lava flows thicken considerably southeastward where they moved over one or more northeast-trending, eroded fault scarps and pooled against the eastern and southeastern topographic walls of the caldera; letter "h" indicates areas that are hydrothermally altered, silicified, and possibly mineralized as mapped by Rowley and others (1986a); maximum exposed thickness is about 1000 feet (300 m).

Tgc **Volcanic rocks of Greenwich Creek** (lower Miocene) – Moderately resistant, medium- to dark-gray, locally vesicular and amygdaloidal, rhyodacitic lava flows with small, sparse phenocrysts of plagioclase, generally subordinate sanidine, and minor pyroxene, biotite, Fe-Ti oxides, and olivine; a late intracaldera unit that is a partial extrusive equivalent of resurgent intrusive rocks related to Monroe Peak caldera; forms one small outcrop in northwest corner of map area that is as much as about 100 feet (30 m) thick; thickens appreciably northward into the Koosharem quadrangle (Rowley and others, 1986b; Doelling and others, in preparation).

Tub, Tubh

Volcanic rocks of Upper Box Creek Reservoir (lower Miocene to upper Oligocene) – Poorly to moderately resistant, reddish-brown, gray, and black lava flows, volcanic mudflow breccia, and minor sandstone and conglomerate interlayered in the upper part of the intracaldera facies of the Osiris Tuff (Toi); contains sparse to moderately abundant phenocrysts of plagioclase, subordinate sanidine, pyroxene, and biotite, and minor Fe-Ti oxides and olivine; deposited during an early phase of the eruptions that led to the voluminous post-Osiris intracaldera lava flows and domes; letter "h" indicates areas that are hydrothermally altered, silicified, and possibly mineralized as mapped by Rowley and others (1986a); maximum exposed thickness about 500 feet (150 m).

Toi, Toih

Osiris Tuff, intracaldera facies (lower Miocene to upper Oligocene) – Poorly to moderately resistant, light-gray and grayish-brown, densely welded, moderately crystal-rich, rhyodacitic ash-flow tuff (a trachyte using the TAS classification scheme of LeBas and others, 1986) that is petrographically similar to the outflow facies (To); fills the lower part of the Monroe Peak caldera, which is the source of the Osiris Tuff (Rowley and others, 1981a; Cunningham and others, 1983; Rowley and others, 1986a); letter "h" indicates areas that are hydrothermally altered, silicified, and possibly mineralized as mapped by Rowley and others (1986a); overlain by intracaldera volcanic rocks of Sage Flat that yielded an ^{40}Ar/^{39}Ar age on sanidine of 23.10 ± 0.09 Ma (UGS and NMGRL, 2019a); maximum exposed thickness is about 330 feet (100 m), but the unit is probably much thicker where it underlies the volcanic rocks of Upper Box Creek Reservoir and elsewhere (Rowley and others, 1986a).

To **Osiris Tuff, outflow facies** (lower Miocene to upper Oligocene) – Resistant, light-gray and grayish-brown, densely welded, moderately crystal-rich, trachyte ash-flow tuff (petrographically a rhyodacite); contains about 20% to 25% phenocrysts of plagioclase, subordinate sanidine and biotite, and minor pyroxene and Fe-Ti oxides (Anderson and Rowley, 1975; Mattox, 2001); forms a simple cooling unit, which in some places includes an upper, light-gray vapor-phase zone and a basal black vitrophyre as much as 10 feet (3 m) thick; forms the uppermost widespread volcanic unit in the map area; forms a prominent ledge and commonly weathers to large rounded boulders; contains drawn-out pumice lenticles; upper part and margins of unit along paleovalleys (such as those of modern-day Riley Canyon and Dog Flat Hollow west and northwest of Loa) locally exhibit steeply dipping flow foliations, rheomorphic features caused by secondary flowage of rock during the last few tens of meters of movement; the preferred age of the Osiris is about 23 Ma based on several analyses (table 1) (Rowley and others, 1994; Ball and others, 2009; UGS and NMGRL, 2019b; Willis and Doelling, 2019; T. Rivera, written communication, June 18, 2019); overlies volcanic rocks of Langdon Mountain and older map units and is locally overlain by gravels of the Sevier River Formation and younger middle Miocene to Pliocene basaltic lava flows; typically about 100 to 150 feet (30–45 m) thick, but as much as about 300 feet (90 m) thick where it fills paleovalleys west of Loa.

The Osiris Tuff erupted from the Monroe Peak caldera, the largest caldera of the Marysvale volcanic field and the youngest of the calc-alkaline sequence (Steven and others, 1984; Rowley and others, 2002). The Osiris Tuff is one of the most widespread and distinctive ash-flow tuffs of the Marysvale volcanic field (Rowley and others, 1994) and has an estimated volume of 60 cubic miles (250 km^3) including its thick intracaldera fill (Cunningham and others, 2007).

Tos **Sandstone and conglomerate associated with the Osiris Tuff** (upper Oligocene) – Brownish-gray, fine- to coarse-grained, biotite-rich sandstone and conglomerate; clasts are subangular to subrounded pebbles and cobbles of intermediate volcanic rocks; weathers to poorly exposed slopes below resistant ledge of Osiris Tuff along Pine Creek southwest of Bicknell Bottoms; possibly a basal surge deposit; as much as about 50 feet (15 m) thick.

Tlmu **Trachyte lava flows of Lake Creek, alluvial, lacustrine, and mass-movement strata related to Sevier gravity slide, breccia of Big Point, and Sevier River Formation, undivided** (upper Oligocene) – Map units undivided on the southwest flank of the Aquarius Plateau (Escalante Mountains) due to poor exposure.

Qtz **Quartz** (lower Miocene to upper Oligocene) – Massive, resistant, white bull quartz mapped associated with hydrothermally altered rocks in and adjacent to the Monroe Peak caldera; exposed thickness as much as several tens of feet.

Tiu **Breccia of Pine Canyon** (upper Oligocene) – Brecciated, fine-grained rock of monzonitic to monzodioritic composition containing veins and infilling of fine- to medium-grained nepheline-bearing diorite and syenite, both exhibiting hydrothermal alteration and zeolitization; Agrell and others (1998, 1999) reported on skarn-like occurrences of magnetite and Al-spinel-rich feldspathoidal rocks, including an olivine-bearing variety and an aluminous, corundum- and hibonite-bearing variety, both with local rare-earth-bearing minerals, and they also noted that the alkaline character of the breccia is unusual in a volcanic field of predominately calc-alkaline rocks, although Nelson (2009) noted that the laccolith clusters on the Colorado Plateau are peralkaline; grossular, diopside, and wollastonite are locally significant and a variety of rare-earth-bearing minerals, such as hibonite, armalcolite, perovskite, and scandian pseudobrookite, as well as sapphires, are present; interpreted by Agrell and others (1999) as an elliptically shaped breccia pipe about 4250 feet (1300 m) in maximum dimension, but reinterpreted here as a northwest-trending dike enlarged at its apparent northwest terminus; mapped at the east edge of the Sevier Plateau, in the northwest corner of the Parker Knoll quadrangle, where it intruded into intertonguing vent facies of the volcanic rocks of Little Table Mountain and those of Langdon Mountain (here not mapped separately) and appears to be related to a shallow, unexposed calc-alkaline intrusion, part of a composite batholith that underlies the central Marysvale volcanic field; four prospect trenches southeast of the dike are in hydrothermally altered lava flows and colluvium, the latter of which contains sparse, eroded fragments of dike rocks, also noted by Agrell and others (1999); Rowley and others (1994) reported a preferred ^{40}Ar/^{39}Ar age of 24.4 ± 1.0 Ma on sanidine from a syenite vein within the dike.

Sevier Gravity Slide

Gravitational collapse of the south flank of the Oligocene to Miocene Marysvale volcanic field produced three gigantic catastrophic gravity slides—the Sevier (SGS), Markagunt (MGS), and Black Mountains (BGS)—that form an overlapping contiguous complex covering an area >3000 mi^2 (>8000 km^2) (Biek and others, 2019; Hacker and others, 2019; Biek and others, 2020). Each gravity slide exhibits the full range of structural features commonly seen in modern landslides, but on a gigantic scale—they are among Earth's largest terrestrial landslides. Gravity slide masses consist mostly of andesitic lava flows, volcaniclastic rocks, and regional ash-flow tuffs that moved as a largely intact sheet along four distinct structural segments: (1) a high-angle breakaway segment, (2) a bedding-plane segment, (3) a ramp segment where the gravity slide cut up-section and the basal fault "daylighted," and (4) a former land-surface segment where the upper plate moved at least 20 miles (32 km) over the landscape (the Sevier gravity slide moved at least 28 miles (45 km). Features such as basal layers (cataclastic breccias) and shears, clastic dikes (injectites), jigsaw puzzle fracturing, and stunning pseudotachylytes (frictionites) indicate high-velocity movement aided by overpressured fluids. The principal zone of failure was in mechanically weak, clay-rich, Brian Head Formation sedimentary strata at the base of the volcanic section.

The gravity slide masses become younger westward, following westward migration of volcanism in the field, and record southward, gravitationally induced catastrophic failure of the southern flank of the volcanic field. The breakaway area of each is overprinted by the largest volcanic features in the field, namely the Monroe Peak and Mount Belknap calderas and the Mineral Mountains, Utah's largest exposed batholith. Failure was preceded by slow gravitational spreading accommodated by the Paunsaugunt thrust fault system, which is rooted in Middle Jurassic evaporite-bearing strata at a depth of ~2 km (Lundin, 1989; Davis, 1997a, 1997b, 1999). SGS emplacement is about 25 Ma, MGS emplacement about 23 Ma, and the BGS was emplaced after 19.5 Ma and likely about 18 Ma (Biek and others, 2019; Loffer and others, 2020).

Biek and others (2019, 2022) provided a history of recent discovery and current understanding of the gravity slides (which are the focus of ongoing research), and a guide to locations of particularly instructive exposures wherein they documented their conclusions about size, distinctive structural features, emplacement ages, and interpreted emplacement mechanisms. These gravity slides remained undiscovered for so long precisely because of their gigantic size and initially confusing mix of extensional, translational, and compressional structures overprinted by subsequent basin-range tectonism.

We call the deposits of the SGS the Sevier megabreccia, a small part of which is exposed at the west margin of the Awapa Plateau in Dry Wash. In this map area, the only truly instructive megabreccia exposures are present in Dry Wash, which Biek and others (2015b) tentatively called the megabreccia of Dry Wash and which we map here as Sevier megabreccia, undivided (Tsm). The east flank of the gravity slide appears to roughly coincide with the modern Paunsaugunt fault zone north of Otter Creek Reservoir, where we depict it as a concealed left-lateral strike-slip fault; this left-lateral strike-slip fault is not a true tectonic fault, rather simply the margin of the SGS. Given megabreccia outcrops in Dry Wash, this fault must continue southward near the foot of the plateau, where it is concealed by modern landslide deposits and eroded away over the Pole Canyon structural high.

The Pole Canyon feature is defined by three areas of older volcanic and pre-volcanic sedimentary strata that are structurally high with respect to nearby areas to the north and south. Near Jones Corral, at the west edge of the Sevier Plateau, this includes a north-tilted panel of Three Creeks Member and younger strata that are >3000 feet (>900 m) higher than correlative exposures in Kingston Canyon a few miles to the north (Rowley and others, 2005). Eastward, in the lower reaches of Pole Canyon east of Antimony, even older Brian Head, Wah Wah Springs and younger strata, locally with intense shearing and cataclasis, are exposed in a small domal structure (Rowley and others, 2005; Loffer, in prep.). And at the east end of the Pole Canyon structural high, in Dry Wash and near Big Point at the west edge of the Awapa Plateau, Wah Wah Springs sits on fluvial and lacustrine strata of Antimony Canyon (Tu); Brian Head strata, present in nearby areas, are missing. We interpret the Pole Canyon structural high as having formed above a blind, south-vergent thrust analogous to the Paunsaugunt thrust faults at the south end of the Sevier Plateau (Biek and others, 2015; Biek and others, 2019). Timing of deformation of the structural high appears to be asynchronous along its length: pre-30 Ma Wah Wah Springs at its east end, and post-Wah Wah Springs but pre-23.1 Ma Osiris Tuff on the Sevier Plateau. A widespread unconformity associated with this structural high separates deformed and undeformed strata on the Sevier Plateau south of Kingston Canyon.

The northern breakaway of the Sevier gravity slide appears to be mostly destroyed by the younger Monroe Peak caldera. Lacking an obvious breakaway fault in this map area, we tentatively interpret the anomalous east-striking Koosharem fault immediately north of this map area as the main breakaway. If this interpretation is correct, Langdon Mountain lava flows there are older than those at Langdon Mountain itself and thus part of the gravity slide. There is much we do not know about this northern part of the gravity slide.

Map units involved in the gravity slide are not deformed or little deformed in most places, so they may be easily correlated with named rock units not transported in the slides or that were mapped and named before recognition of the slides. Therefore, rocks interpreted to be involved in the Sevier gravity slide are designated with a symbol consisting of a prefix "Ts," followed in parentheses by the symbol for the named undeformed rock unit, for example, Ts(Tla)—the alluvial facies of the Langdon Mountain Formation as part of the Sevier gravity slide. We include here deposits that represent younger erosion of the Sevier gravity slide and therefore are not themselves deformed, namely the breccia of Big Point (Tlbp) and alluvial, lacustrine and mass-movement strata related to the Sevier gravity slide (Tsmx).

Tlbp **Breccia of Big Point** (upper Oligocene) – Gray, angular, clast-supported, cobble- and boulder-size blocks apparently mostly of the trachyte lava flows of Lake Creek (Tlc), but locally including volcanic rocks of Signal Peak (Tsp) and andesite likely of the Mount Dutton Formation (Tda), that form a resistant ledge at the southwest edge of the Awapa Plateau yet weather to poorly exposed, rounded, rubble-covered hills atop the plateau; locally, the breccia is highly porous and permeable and partly cemented by calcite; at Big Point and at the head of Antimony Canyon, resembles a lava flow breccia developed on the trachyte lava flows of Lake Creek, yet southward, the lava flows and breccia of Big Point are clearly separated by a northward-thinning wedge of post-Sevier megabreccia alluvial and lacustrine strata (Tsmx); undated; exact origin not clear but most of the deposit is interpreted to represent debris shed from the Sevier gravity slide by mass wasting; as much as 130 feet (40 m) thick.

Tsmx **Alluvial, lacustrine, and mass-movement strata eroded from Sevier gravity slide** (upper Oligocene) – Mapped in the Pollywog Lake area on top of the Awapa Plateau east of Antimony, as well as in nearby cliffs at the west edge of the plateau. The nearest outcrops of gravity slide rocks are nearly 10 miles (16 km) to the northwest in Dry Wash and in fault blocks of the Paunsaugunt fault zone and 1600 feet (490 m) below the elevation of these unusual deposits. Locally disconformably overlain by undated basaltic lava flows that are probably 5 to 7 Ma. **Alluvial and lacustrine strata:** White, non-resistant, interbedded tuffaceous sandstone, siltstone, mudstone, and cherty limestone; at the top of this unit west of Dry Hollow, contains angular or uncommonly subrounded, cobble-size clasts of dacitic ash-flow tuff, which are locally brecciated and likely from the Three Creeks Tuff Member; the limestone is laminated, contains reddish-brown and yellow chert nodules, and weathers to poorly exposed, discontinuous ledges; fine-grained tuffaceous intervals locally contain thin lenses of reddish-brown, gray, and brown chalcedony similar to that in the Brian Head Formation; near Pollywog Lake, the top of the map unit consists of light-pinkish-brown, unwelded, pumice-lithic tuff about 20 feet (6 m) thick; likely deposited in a small, locally ponded basin related to emplacement of the Sevier gravity slide (Biek and others, 2019); west of Pollywog Lake and west of Dry Hollow map unit concordantly overlies the trachyte lava flows of Lake Creek and volcanic rocks of Signal Peak, and underlies breccia of Big Point, as much as about 100 feet (30 m) thick. **Mass-movement strata** are mapped in two separate areas: **(1)** Two miles (3 km) east of Pollywog Lake, the map unit contains blocks of apparent Brian Head Formation (white, tuffaceous mudstone and chalcedony), Buckskin Breccia (white, crystal-rich, poorly welded lithic tuff with abundant quartz monzonite porphyry clasts), and probably the Three Creeks Tuff Member (crushed and sheared pink dacite ash-flow tuff); also contains silica-cemented, reddish-orange and reddish-brown conglomerate and medium- to coarse-grained quartzose sandstone with rounded to subangular quartzite and limestone pebbles but no igneous clasts; this conglomerate, perhaps derived from the conglomerate at Boat Mesa, includes abundant "jigsaw" clasts indicative of gravity slide emplacement (see, for example, Biek and others, 2019); about 50 feet (15 m) thick. **(2)** In Lost Spring Draw about 2 miles (3 km) south of Pollywog Lake, the map unit consists of unconsolidated, unsorted, clay- to boulder-size material of multiple lithologies, including a variety of subrounded cobbles and boulders of intermediate volcanic rock (including apparent trachyte lava flows of Lake Creek), angular to subrounded cobbles to boulders of pinkish-brown, crystal-rich, dacitic ash-flow tuff (probably the Three Creeks Tuff Member, some of which is sheared and striated), angular blocks of Claron-like limestone and Brian Head tuffaceous mudstone and chalcedony as much as several meters in size, and angular to subrounded pebbles to small blocks of monzonite porphyry likely from the Buckskin Breccia; some exposures may be of fluvial origin, but most of the deposit is clearly unsorted and likely of mass-movement origin; as much as about 70 feet (21 m) thick.

South of Big Point along the southwest margin of the Awapa Plateau, similar lithologies are locally present in basal volcanic rocks of Langdon Mountain (alluvial facies, Tla). Although not mapped separately here due to scale and their discovery late in this mapping effort, such lithologies suggest that erosional debris of the Sevier gravity slide is more widespread than currently mapped. This debris is clearly overlain by a thickness of only about 300 feet (90 m) of Langdon Mountain alluvial facies strata (Tla) at Big Point, showing that here, the apparently upper part of Langdon strata postdate Sevier gravity slide emplacement at about 25.1 Ma.

Tsm, Tsm?

Sevier megabreccia, undivided (upper Oligocene) – Well exposed in Dry Wash northeast of Antimony where it is ledge-forming, intensely fractured and sheared, mostly gray and greenish-gray volcanic mudflow breccia of uncertain affinity, lesser white to light-gray, volcanic conglomerate and sandstone that lacks quartzite clasts, resistant pebble- to cobble-size monzonite clasts likely from the Buckskin Breccia, and Three Creeks Tuff Member; cut by grayish-brown to grayish-red clastic dikes of ultracataclasite in multiple orientations (but mostly subvertical) and as much as 1 foot (0.3 m) wide and locally extending at least 80 feet (25 m) vertically into the slide mass; a basal shear plane is developed on the profoundly planar top of 26 Ma Buckskin Breccia with grooves and striations oriented roughly N. 10° W. and Riedel shears that indicate emplacement from north to south; query indicates uncertain designation of a block caught between splays of the Paunsaugunt fault zone about one mile (1.6 km) northwest of the Dry Wash block; as much as 260 feet (80 m) thick.

Ts(Tll) **Sevier megabreccia, volcanic rocks of Langdon Mountain, lava flow facies component** (upper Oligocene) – Mapped north of Greenwich where these rocks are inferred to predate emplacement of the Sevier gravity slide

Ts(Tlah)

Sevier megabreccia, volcanic rocks of Langdon Mountain, alluvial facies hydrothermally altered component (upper Oligocene) – Mapped at the east edge of the Sevier Plateau where these rocks are inferred to predate emplacement of the Sevier gravity slide; 'h' indicates hydrothermal alteration in proximity to the Monroe Peak caldera.

Ts(Tla) **Sevier megabreccia, volcanic rocks of Langdon Mountain, alluvial facies component** (upper Oligocene) – Mapped on the Sevier Plateau and southern Grass Valley where these rocks are deformed or inferred to have been carried in the Sevier gravity slide and therefore were originally deposited before gravity sliding. It is likely that the pre-slide part of the map unit makes up part of the thick deposits on the western Awapa Plateau scarp, but with no evidence of the slide having reached that far to the east, any contact between pre-slide and post-slide rocks cannot be mapped.

Ts(Twl) **Sevier megabreccia, volcanic rocks of Willow Spring, lava flow facies component** (upper Oligocene) – Mapped on the Sevier Plateau west of Greenwich where these rocks are inferred to predate emplacement of the Sevier gravity slide; see unit Twl description.

Ts(Twa) **Sevier megabreccia, volcanic rocks of Willow Spring, alluvial facies component** (upper Oligocene) – Mapped on the Sevier Plateau west of Greenwich where these rocks are inferred to predate emplacement of the Sevier gravity slide; see unit Twa description.

Ts(Tlt) **Sevier megabreccia, volcanic rocks of Little Table component** (upper Oligocene) – Mapped at the east edge of the Sevier Plateau where these rocks are inferred to predate emplacement of the Sevier gravity slide; see unit Tlt description.

Ts(Tlc) **Sevier megabreccia, trachyte lava flows of Lake Creek component** (upper Oligocene) – Mapped near Otter Creek Reservoir where these rocks are deeply altered, and southward where they are unaltered in Black Canyon, and in both areas inferred to predate emplacement of the Sevier gravity slide; as much as about 300 feet (90 m) thick.

Ts(Tsp?)

Sevier megabreccia, volcanic rocks of Signal Peak component (upper Oligocene) – Small, deeply altered and poorly exposed block east of Otter Creek Reservoir; incomplete thickness is several tens of feet.

Ts(Tnw)

Sevier megabreccia, Wah Wah Springs Formation component (upper Oligocene) – Fault-bounded, near-vertical, intensely fractured and sheared blocks of apparent Wah Wah Springs Formation caught between splays of the Paunsaugunt fault zone about one mile (1.6 km) northwest of the Dry Wash block.

Ts(Tbh) **Sevier megabreccia, Brian Head Formation component** (upper Oligocene) – White to light-gray, tuffaceous mudstone, fine-grained sandstone, and conglomerate with rounded to subrounded, mostly andesitic to dacitic clasts and fewer rounded boulders of quartzite caught between splays of the Paunsaugunt fault zone about one mile (1.6 km) northwest of the Dry Wash block; see unit Tbh description.

Tll **Volcanic rocks of Langdon Mountain, lava flow facies** (upper Oligocene) – Resistant, locally glassy, gray to greenish-gray dacitic lava flows exposed north of Greenwich; the rock consists of commonly large phenocrysts of plagioclase, subordinate hornblende, and lesser pyroxene and opaque minerals in a devitrified glass groundmass; lava flows southwest of Greenwich, high on the Sevier Plateau at Langdon Mountain in the adjacent Beaver 30' x 60' quadrangle and probably younger than those mapped near Koosharem, yielded a preliminary $^{40}Ar/^{39}Ar$ age on plagioclase of 24.68 ± 0.32 Ma (Tiffany Rivera, written communication, January 5, 2022); as much as about 300 feet (90 m) thick in this map area.

Tla, Tlah

Volcanic rocks of Langdon Mountain, alluvial facies (Oligocene) – Poorly to moderately resistant, mostly dacitic but locally andesitic volcanic mudflow breccia (lahar deposits) and subordinate sandstone and conglomerate; the dominant lithology of the clasts is low to moderate phenocrysts of plagioclase and generally subordinate conspicuous hornblende, with mostly lesser pyroxene, in a glassy to aphanitic groundmass; letter "h" indicates areas that are hydrothermally altered, silicified, and possibly mineralized in the vicinity of the Monroe Peak caldera on the Sevier Plateau; overall map unit is brown or grayish brown, but east of Otter Creek Reservoir where it overlies deep reddish- and yellowish-brown, altered trachyte lava flows of Lake Creek (Tlc), the Langdon matrix in the lower 200 feet (60 m) of the map unit is deep reddish brown but clasts are unaltered—the red-brown color may be a result of early diagenetic alteration much like that which occurs with many of Utah's Mesozoic sandstones (see, for example, Chan and others, 2000; Chan and Parry, 2002; Beitler and others, 2003); locally includes volumetrically minor, thin dacitic lava flows on the Awapa Plateau, but on the Sevier Plateau includes volumetrically significant lava flows, commonly hydrothermally altered, here not mapped separately due to poor exposure; in the Parker Knoll quadrangle, south of Rock Canyon in sections 13, 14, 23, and 24, T. 29 S., R. 2 W., unit includes basaltic andesite lava flows with pyroxene phenocrysts as much as 0.75 inch (2 cm) long; the map unit is well exposed along the western escarpment of the Awapa Plateau, but typically weathers to regolith-covered, low, rounded hills elsewhere; on the central and southern Awapa Plateau typically overlain by the Osiris Tuff; deposited principally as lahars sourced from one or more stratovolcanoes in the central Sevier Plateau (Rowley, 1979; Rowley and others, 1979, 1981a; Mattox, 1991) likely destroyed by development of the Monroe Peak caldera; Mattox (2001) reported that the unit is in excess of 2600 feet (800 m) thick at Parker Mountain on the west-central flank of the Awapa Plateau, a thickness that suggests that stratovolcano sources are nearby; deposition of the map unit spans the age of the Sevier gravity slide, but without deformed rocks from the slide, any contact or unconformity separating pre- and post-slide rocks has not been identified; map patterns show that it thins dramatically southward to about 200 feet (60 m) thick south of Big Point on the southwestern flank of the plateau.

Near Big Point on the southwest flank of the Awapa Plateau, lower 100 feet (30 m) contains erosional debris (including rounded clasts of deformed volcanic rocks of Signal Peak, of the crystal-rich dacite (Wah Wah Springs or Three Creeks), and of quartzite pebbles and cobbles apparently shed from erosion of the Sevier gravity slide, and so Langdon strata there appear to post-date slide emplacement at about 25.1 Ma. High on the Sevier Plateau at Langdon Mountain in the adjacent Beaver 30' x 60' quadrangle, an overlying Langdon Mountain lava flow yielded a preliminary $^{40}Ar/^{39}Ar$ plateau age on plagioclase of 24.68 ± 0.32 Ma (Tiffany Rivera, written communication, January 5, 2022). Thus, the best age constraints available suggest that the Langdon alluvial facies was deposited between 25.1 Ma and 24.7 Ma.

However, although undated, Langdon alluvial strata on the central and northern Awapa Plateau, and on the Sevier Plateau, appear to in part pre-date slide emplacement at 25.1 Ma. We recognize numerous areas of strongly deformed (sheared outcrops and abundant "jigsaw" clasts) Langdon alluvial strata in Grass Valley and on the Sevier Plateau. Some such outcrops may have resulted from intraformational debris-avalanches during Langdon deposition, but they appear too widespread, especially compared to similar though rare deposits known from Mount Dutton strata. We tentatively interpret this deformation to be due to emplacement of the Sevier gravity slide.

Tlc **Trachyte lava flows of Lake Creek** (upper Oligocene) – Gray, dense, phenocryst-poor, trachyte lava flows with 10% to 25% phenocrysts of plagioclase, and sparse pyroxene and Fe-Ti oxides commonly in a glassy or fine-grained matrix; locally exhibits pronounced platy flow foliation and small flattened gas vesicles, flow breccia, and steep flow folds; well exposed in Graveyard Hollow north of Loa where it is at least 450 feet (135 m) thick beneath the Osiris Tuff; on top of the Awapa Plateau, commonly weathers to gently rolling, regolith-covered slopes that, from a distance, are difficult to distinguish from those developed on the volcanic rocks of Langdon Mountain or the Sevier River Formation; also mapped in a ledge at the south end of Black Canyon where it is about 50 feet (15 m) thick and may include the breccia of Big Point and where it is overlain by several tens of feet of Mount Dutton alluvial facies strata below the Osiris Tuff; name from Bailey and others (2007) and Ball and others (2009), who interpreted the unit as a series of ash-flow tuffs, but based on additional petrologic studies and fieldwork we now understand the unit to be several chemically and petrographically similar lava flows, an interpretation shared by Williams and Hackman (1971) and Mattox (1991, 2001); major- and trace-element discrimination diagrams of the map unit (and of samples identified as tuff of Tibadore Canyon, Antimony Tuff Member, and tuff of Albinus Canyon elsewhere in the region) show that these units cluster remarkably tightly (table 4); on the northern Awapa Plateau and Fish Lake Plateau, map unit typically overlies the volcanic rocks of Signal Peak, but southward it interfingers with lahar deposits of the volcanic rocks of Langdon Mountain; Mattox (1991) reported an anomalously young K-Ar age of 23.1 ± 1.0 Ma for his sample AP119 in Wildcat Canyon on the east-central Awapa Plateau; however, Bailey and Marchetti (in preparation; UGS and NIGL, 2012) reported ^{40}Ar/^{39}Ar ages of 25.68 ± 0.19 Ma (groundmass concentrate) and our preferred age of 25.13 ± 0.02 Ma (sanidine) for their trachyte of Lake Creek on the Fish Lake Plateau; we recently obtained a preliminary ^{40}Ar/^{39}Ar plateau age on plagioclase of 25.29 ± 0.14 Ma (Tiffany Rivera, Westminster College, written communication, January 5, 2022 , see also Holliday and others, 2019) on the volcanic rocks of Signal Peak, which directly underlie these trachyte lava flows in the Annabella Hills on the north side of the Marysvale volcanic field; as much as about 500 feet (150 m) thick on the Awapa Plateau, and about 500 feet (150 m) thick at Fish Lake Hightop (Bailey and Marchetti, in preparation), north of this map area.

The trachyte lava flows of Lake Creek have a similar chemistry, age, and petrography to several units in the Marysvale volcanic field, and thus it has a complicated nomenclatural history as multiple researchers worked to sort out its relationships. Biek and others (2015b), Kuehne and Doelling (2016), and Willis and Doelling (2019) carried the nomenclature of Bailey and others (2007) into areas near the Fishlake Plateau, inadvertently lumping multiple units. However, further research shows that the trachyte lava flows of Lake Creek occupy a narrow stratigraphic interval during which multiple lava flows and at least four relatively small ash-flow tuffs erupted from the northeastern Marysvale volcanic field, all within a short span of time. Rowley and others (in preparation) show that the older three moderately welded ash-flow tuffs, present only on the Sevier Plateau where they are known as the tuff of Tibadore Canyon and local tuffs within the alluvial facies of the Mount Dutton Formation, are deformed by the Sevier gravity slide, whereas the youngest, the densely welded Antimony Tuff Member, postdates slide emplacement. The vent or vents of these ash-flow tuffs is not apparent, which may indicate that their magma source was deep in the crust and thus never expressed by a typical collapse caldera (Ekren and others, 1984). Trachyte lava flows of Lake Creek appear to be restricted to the Awapa and Fishlake Plateaus and Grass Valley. New detrital zircon geochronology supports the hypothesis that eruption of the tuff of Tibadore Canyon may be linked to emplacement of the Sevier gravity slide (Loffer and others, 2020; see also Biek and others, 2019).

There is disagreement between the authors of this map as to the identification of the trachyte lava flows of Lake Creek as shown on plate 1, especially along the west margin of the Awapa Plateau and in Grass Valley. Our disagreement arises from the difficulty in distinguishing some ash-flow tuffs from otherwise similar lava flows, a problem first worked on by other geologists, including co-author Rowley, in southwest Utah and elsewhere in the world beginning in the 1960s (Mackin, 1960; Ross and Smith, 1961; Cook, 1965, 1966; Ekren and others, 1984; Andrews and Branney, 2005; and Geissman and others, 2010). This problem gets at the very heart of the inferred style of the volcanic eruptions that produced these sometimes-enigmatic volcanic units: explosive ash-flow tuff eruptions versus effusive lava flows. The problem is exacerbated by the well-known fact that densely welded, phenocryst-poor ash-flow tuffs commonly flow during their last several tens of meters of emplacement, thus creating flow textures common to lava flows; these are known as rheomorphic ignimbrites, or less commonly as tufflavas. For this Loa map, we look for eutaxitic texture, glass shards, flattened pumice, lithic fragments, and broken phenocrysts as hallmarks of ash-flow tuffs. In contrast, as we define them here, the trachyte lava flows have far fewer broken phenocrysts and a groundmass not of shards but rather mostly plagioclase microlites that give the matrix a microscopic felted or locally trachytic texture. Still, thin section and outcrop characteristics are not everywhere so clear as expressed by that duality, thus our uncertainty, which is compounded yet again by the fact that these various phenocryst-poor units occupy a narrow stratigraphic interval of about 25 to 25.2 Ma. To be clear, Rowley considers that, based principally on petrography and modal analyses, some of the rocks mapped as the trachyte lava flows of Lake Creek, namely those on the west margin of the Awapa Plateau east of Antimony (in upper Dry Creek Wash, the Big Point area, and southwest of Pollywog Lake), and those west of Otter Creek Reservoir, are thick sequences of the tuff of Tibadore Canyon that drained southeast off its unknown source in the Marysvale field to pool in lowlands and fuse, as was the case for the thick sequence of the Osiris Tuff exposed just west of Loa. Furthermore, Rowley considers the exposures at the south end of Black Canyon to be Antimony Tuff Member. Look to our upcoming work on the adjacent Beaver 30' x 60' quadrangle, which exposes a fuller section of undisputed ash-flow tuffs and which is now (2022) in the final stages of compilation and revision, for a fuller discussion of this problem.

Tda **Mount Dutton Formation, alluvial facies** (upper Oligocene) – Light- to dark-gray and brown, crystal-poor, andesitic to dacitic volcanic mudflow breccia and lesser interbedded volcanic conglomerate; rock characterized by an aphanitic groundmass containing few small phenocrysts, primarily pyroxene with or without plagioclase; in Black Canyon, along SR-22 in section 11, T. 32 S., R. 2 W., also contains a resistant ledge of lithic ash-flow tuff about 15 feet (5 m) thick; in one small exposure below Big Point at the southwest flank of the Awapa Plateau, consists of poorly to moderately cemented, heterolithic volcanic mudflow breccia with a light-gray ashy and sandy matrix; the Mount Dutton Formation is poorly and incompletely exposed in Black Canyon where it is as much as about 200 feet (60 m) thick.

Anderson and Rowley (1975) defined the Mount Dutton Formation as consisting of most of the rocks exposed on the south flank of the Marysvale volcanic field and divided it into complexly interfingering and cross-cutting vent and alluvial facies derived from clustered stratovolcanoes and dikes. The volcanic rocks of Langdon Mountain were also derived from one or more stratovolcanoes of the central Marysvale volcanic field, and although they are characterized by predominant hornblende rather than pyroxene as are Mount Dutton strata, we are unable to readily and reliably differentiate the two units in the field at this map scale. Immediately west of this map area, in the east-central Beaver 30' x 60' quadrangle, Rowley and others (2005) mapped the volcanic rocks of Langdon Mountain stratigraphically above those of the Mount Dutton Formation. Both units underlie the 23 Ma Osiris Tuff. In the Loa 30' x 60' quadrangle, we restrict Mount Dutton strata to the Black Canyon area and assign similar volcanic mudflow strata and volcanic conglomerate of the Awapa Plateau to the volcanic rocks of Langdon Mountain, realizing the arbitrary nature of our designations and that the two formations may interfinger over a broad area. In Black Canyon, Mount Dutton strata are commonly well-bedded, clast-supported conglomerate containing rounded clasts, what we consider to be the eastern, distal fluvial edge of the alluvial facies (Rowley, 1968).

The Marysvale volcanic field is one of several voluminous calc-alkaline, subduction-related volcanic centers and underlying source batholiths that characterized the western U.S. from Oligocene to Miocene time at this latitude (Lipman and others, 1972; Rowley and others, 1998; Rowley and Dixon, 2001). Fleck and others (1975) and Rowley and others (1994) reported several K-Ar ages of 23 to 30 Ma on rocks of the coeval vent facies. The alluvial facies is about 2000 feet (600 m) thick on the south end of the Sevier Plateau (Rowley and others, 1987; Biek and others, 2015a) and is at least 6000 feet (2000 m) thick in the central Sevier Plateau (Anderson and others, 1990a, 1990b; Rowley and others, 2005). Individual mudflows and other rock units pinch out radially from an east-trending string of stratovolcanoes along the south part of the Marysvale volcanic field.

Tdlt **Mount Dutton Formation, local ash-flow tuff** (upper Oligocene) – Gray, densely welded, phenocryst-poor trachyte ash-flow tuff and flow breccia; exposed at the entrance to Poison Creek southwest of Antimony where it underlies fluvial strata like that exposed in Black Canyon and assigned to the Mount Dutton Formation; incomplete thickness is about 50 feet (15 m).

Twl **Volcanic rocks of Willow Spring, lava flow facies** (upper Oligocene) – Only mapped with Sevier Megabreccia, unit Ts(Twl); moderately resistant, pinkish-gray and gray, basaltic to andesitic lava flows and subordinate volcanic mudflow breccia; contains sparse to moderately abundant phenocrysts of pyroxene, subordinate Fe-Ti oxides, local hornblende, and minor plagioclase and olivine; part of a stratovolcano sequence of pyroxene-bearing rocks exposed in the Sevier Plateau south of the Monroe Peak caldera; many exposures are brecciated and sheared, which we interpret to be largely due to emplacement of the Sevier gravity slide; maximum thickness about 460 feet (140 m).

Twa **Volcanic rocks of Willow Spring, alluvial facies** (upper Oligocene) – Only mapped with Sevier Megabreccia, unit Ts(Twa); poorly to moderately resistant, pinkish-gray, gray, and brownish-gray, andesitic volcanic mudflow breccia and subordinate lava flows, sandstone, and conglomerate; clasts are andesitic to dacitic and generally glassy with phenocrysts of plagioclase, pyroxene, and minor Fe-Ti oxides; part of a stratovolcano sequence of pyroxene-bearing rocks exposed in the Sevier Plateau south of the Monroe Peak caldera; maximum thickness at least 1650 feet (500 m).

Tlt **Volcanic rocks of Little Table** (upper Oligocene) – Only mapped with Sevier Megabreccia, unit Ts(Tlt); mostly resistant, tan, brown, gray, brownish-red, and greenish-gray, amygdaloidal, crystal-poor, andesite lava flows and flow breccia and intertongued volcanic mudflow breccia; of vent-facies and alluvial-facies origin (Anderson and Rowley, 1975), separated in detailed mapping (Cunningham and others, 1983); interpreted to be derived from a shield-volcano complex that intertongues with Mount Dutton and Langdon Mountain strata; maximum thickness 2500 feet (750 m).

Tsps **Volcanic rocks of Signal Peak, sedimentary strata** (upper Oligocene) – Non-resistant, light-yellowish-brown and reddish-brown, fine-grained sandstone and siltstone; mapped in Dry Valley northwest of Loa, where it underlies or is interbedded with porphyritic trachyandesite (latite) of the volcanic rocks of Signal Peak; may represent ponded basin fill deposits related to apparent intraformational Signal Peak landslide deposits exposed along the northside of Allred Point; at least 40 feet (12 m) thick.

Tsp **Volcanic rocks of Signal Peak** (upper Oligocene) – Gray, weathering to brownish gray and black, porphyritic trachyandesite (latite) with 25% to 35% phenocrysts of plagioclase and pyroxene and minor olivine; plagioclase phenocrysts, commonly 0.4 inch (1 cm) in length, and slightly smaller pyroxene phenocrysts are typically present in subequal amounts, although some exposures show prominent plagioclase and smaller and fewer pyroxene phenocrysts; weathers to rough, dark-colored, bouldery outcrops; major- and trace-element discrimination diagrams show little variation between samples apart from the large-ion lithophile elements Ba and Sr, which are enriched in the northern Awapa Plateau as also noted by Mattox (1991); several ^{40}Ar/^{39}Ar ages for this unit mostly of about 25 to 26 Ma, but because this unit clearly underlies the Antimony Tuff Member, our preferred age is pre-25.13 to 26 Ma (given its thickness and extent, map unit may span about one million years of time); forms the cap of Boulder Mountain and extensive areas on the Awapa and Aquarius Plateaus, and also caps Thousand Lake Mountain immediately east of the map area; query indicates uncertain correlation of deeply altered rocks east of Otter Creek Reservoir that may be part of the Sevier gravity slide; on the north side of Allred Point north of Loa, roadcuts reveal tilted and brecciated Signal Peak rocks cut by clastic dikes, which we interpret to be an intraformational landslide deposit; generally thins southward from the Fish Lake Plateau where Marchetti and others (2013) reported that the unit is locally in excess of 1000 feet (300 m) thick; Smith and others (1963) reported this unit to be 475 feet (145 m) thick at Boulder Mountain, but we find it to be about 600 feet (200 m) thick along its south flank; it is as much as 500 feet (150 m) thick at Big Hollow on the central Awapa Plateau (Mattox, 1991, 2001).

This unit was informally called the trachyandesite or latite of Johnson Valley by Bailey and others (2007) in their initial mapping of the Fish Lake Plateau. Concurrent and subsequent mapping by Biek (2016), Biek and others (2015b, 2017), Kuehne and Doelling (2016), and Willis and Doelling (2019) carried this nomenclature into nearby areas. However, further research—including in collaboration with Willis, who is mapping these rocks to the north (written communication, July 9, 2021)—suggests that these are the same rocks mapped by Cunningham and others (1983), Rowley and others (1986b, 2002), and Hintze and others (2008) in the Sevier Plateau as the informally named volcanic rocks of Signal Peak, which are thought to be mostly vent facies (lava flows) about 2100 feet (650 m) thick derived from a shield volcano complex in the northern Sevier Plateau. Given precedence of this earlier name, we abandon the name latite of Johnson Valley in favor of the informally named volcanic rocks of Signal Peak.

Smith and others (1963) noted two to three thick lava flows at Boulder Mountain, which we now call the volcanic rocks of Signal Peak. Williams and Hackman (1971) called these rocks basaltic andesite and noted their widespread occurrence in the eastern Marysvale volcanic field. On the Fish Lake Plateau, these rocks were originally thought to be an ash-flow tuff likely consisting of several cooling units (Ball and others, 2009), but vitrophyres are absent, thin sections reveal no glass shards, and it appears unlike other ash-flow tuffs of the Marysvale volcanic field or of calderas farther west near the

Utah-Nevada border. We interpret this map unit as multiple, thick, widespread lava flows of exceptionally similar chemistry and petrography. Vent areas are unknown but given the then-known distribution of the volcanic rocks of Signal Peak, Cunningham and others (1983) and Rowley and others (1986b, 2002) suggested sources in the northern Sevier Plateau. Their widespread occurrence along the entire east edge of the Marysvale field suggests that this collection of lava flows may represent fissure eruptions rather than eruptions from a cluster of topographically high vents.

Tbb, Tbb?

Buckskin Breccia (upper Oligocene) – Light-brown and pinkish-brown, poorly welded lithic tuff with abundant pebble- to small-cobble-size quartz monzonite porphyry clasts; clasts are mineralogically and chemically similar to the Spry intrusion, which is a laccolith (Anderson and Rowley, 1975; Rowley and others, 2005); map unit may be reworked by streams as mudflow deposits, and regionally map unit includes dacitic lava flows, volcanic mudflow breccia, conglomerate, and sandstone (Anderson and Rowley, 1975; Yannacci, 1986); mapped only along the middle reaches of Dry Wash east of Otter Creek Reservoir where it disconformably overlies an upper, unnamed unit of Tertiary sedimentary strata (Tsu) and immediately underlies the Sevier gravity slide (Tms); query indicates likely outcrop not field checked; about 26 Ma based on several 26 Ma ages of the Spry intrusion and related volcanic rocks (Anderson and others, 1990b; Rowley and others, 1994; UGS and AtoZ, 2013); about 15 to 30 feet (5–9 m) thick.

Tsdb **Tertiary sedimentary strata, Dipping Vat Formation, and Three Creeks Tuff Member of the Bullion Canyon Volcanics, undivided** (Oligocene to Eocene) – Only used as a stacked unit QTms(Tsdb) involved in large landslide complexes north of Bicknell, in the hanging wall of the Thousand Lake fault zone; combined thickness is at least 900 feet (275 m).

Tbu **Bullion Canyon Volcanics, undivided** (Oligocene) – Pale- to reddish-brown volcanic mudflow (lahar) deposits with large blocks of dacitic tuff (possibly of the 27 Ma Three Creeks Tuff Member of Bullion Canyon Volcanics); exposed east of Bicknell in a steeply west-dipping panel caught between splays of the Thousand Lake fault zone, where it is present below volcanic rocks of Signal Peak, and also present immediately to the southeast; the nature of its upper contact is uncertain but likely of Pliocene or Quaternary landslide origin; unit is also mapped at Saddle Knoll south of Bicknell where it is a brecciated, light-gray, coarse-grained porphyry of unknown correlation, with plagioclase, quartz, and biotite phenocrysts in a coarse-grained groundmass, and immediately northeast of Saddle Knoll where this unknown porphyry and intensely brecciated blocks of volcaniclastic strata, Carmel Formation, and Tertiary sedimentary strata are juxtaposed in a fault sliver of the Thousand Lake fault zone; this latter exposure includes resistant, light-brownish-gray, silica-cemented angular blocks possibly of the Shinarump Member of the Chinle Formation; also mapped in a poorly exposed fault block west of Utah Highway 24 near the north edge of the map area where it overlies apparent Bullion Canyon Volcanics; erupted and eroded from several clustered stratovolcanoes in the northern Marysvale volcanic field (for example, Rowley and others, 1994) and ranges in age from about 23 to 32 Ma (Fleck and others,1975; Rowley and others, 1994, 1998; Cunningham and others, 2007; Willis and Doelling, 2019; UGS unpublished data); as much as about 40 feet (12 m) thick near Bicknell and probably about 150 feet (45 m) thick at Saddle Knoll.

Unit also includes reddish-brown volcanic mudflow breccia, lava flows, ash-flow tuff, and conglomerate and sandstone of mostly dacitic and andesitic composition as a stacked unit involved in large landslide complexes QTms(Tsdb) north of Bicknell, in the hanging wall of the Thousand Lake fault zone.

Tsu, Tsu?

Tertiary sedimentary strata, upper unit (Oligocene) – Conglomerate, pebbly sandstone, siltstone, and mudstone that forms slopes in the middle reaches of Dry Wash east of Otter Creek Reservoir where it disconformably overlies Wah Wah Springs Formation and underlies lithic tuff of Buckskin Breccia; overall yellowish-brown in color with thin reddish-brown finer grained lenses in the upper half; conglomerate makes up the lower one-third of map unit with clasts that are about 90% white, tan, and maroon orthoquartzite and 10% intermediate volcanic rocks; clasts of limestone and black chert are apparently absent; clasts are well rounded and mostly cobble and pebble size but as large as 1.5 feet (0.3 m) in diameter; upper part of map unit contains poorly exposed, fine- to medium-grained sandstone, pebbly sandstone, siltstone, and mudstone of yellowish- to reddish-brown hues; query indicates likely sedimentary strata not field checked; as much as about 100 feet (30 m) thick.

Tnw, Tnw?

Wah Wah Springs Formation of Needles Range Group (lower Oligocene) – Pale-red to grayish-orange-pink, moderately welded, crystal-rich, dacitic ash-flow tuff; phenocrysts of plagioclase, hornblende, and biotite (plus minor quartz, Fe-Ti oxides, and sanidine) constitute about 40% of the rock; weathered surfaces reveal common, iron-stained, flattened, and small cavities that may have been gas vesicles rather than pumice fragments; unlike petrographically and chemically similar 27 Ma Three Creeks Tuff exposed in nearby Kingston Canyon, Wah Wah Springs contains essentially no rock fragments or conspicuous large pumice; vitrophyre only locally present but is well developed in NW1/4 section 32, T. 30 S., R. 1 W.; mapped along the middle reaches of Dry Wash east of Otter Creek Reservoir where it forms a prominent ledge on the north side of the canyon and where in northern and western exposures is disconformably overlain by quartzite cobble to boulder conglomerate, pebbly sandstone, and mudstone (map unit Tsu), and in southern exposures by an unmapped 3- to 6-foot-thick (1–2 m) travertine above which are volcanic mudflow deposits of Langdon Mountain (Tla) as part of Quaternary landslides; also mapped west of Big Point where, as in Dry Wash, it disconformably overlies fluvial and lacustrine strata of Antimony Canyon (Tu); query indicates likely Wah Wah Springs ledge not field checked; the abundance of hornblende over biotite is unique among Great Basin ash-flow tuffs; derived from the Indian Peak caldera of the 27 to 32 Ma Indian Peak caldera complex that straddles the Utah-Nevada border (Best and others, 1989a, 1989b, 2013); today, the Wah Wah Springs covers at least 8500 square miles (22,000 km^2) with an estimated volume of as much as about 720 cubic miles (3000 km^3) (Best and others, 1989a); about 30.0 Ma on the basis of many K-Ar and ^{40}Ar/^{39}Ar age determinations (Best and Grant, 1987; Best and others, 1989a, 1989b; Rowley and others, 1994; Best and others, 2013); Best and others (2013) reported a thickness of 52 feet (16 m) in Dry Wash.

Tmm, Tmm?

Volcanic rocks of Mill Meadow Reservoir (lower Oligocene? to upper Eocene) (temporary name, see note below) – Poorly exposed east of Mill Meadow Reservoir where it consists of lava flows, volcanic mudflow breccia, and minor lithic ash-flow tuff; lava flows contain prominent pyroxene and plagioclase phenocrysts in a medium-grained groundmass and so are similar to volcanic rocks of Signal Peak; includes ledge-forming, 10- to 15-foot-thick (3–5 m), reddish-brown lithic ash-flow tuff with a glassy matrix (sample L062015-1); query indicates uncertain designation of small, poor exposure that may be trachyte lava flows of Lake Creek; biotite from an ash layer yielded an isochron age of 36.53 ± 0.14 Ma (sample FR071708-1 of Marchetti and others, 2013; UGS and NIGL, 2012); incomplete thickness is about 100 feet (30 m).

Volcanic rocks of Mill Meadow Reservoir may be better assigned to an older part of the Bullion Canyon Volcanics. Bullion Canyon strata include lava flows, volcanic mudflow breccia, ash-flow tuff, and ash-rich sedimentary deposits of intermediate composition derived from multiple stratovolcanoes in the northern Marysvale volcanic field between about 30 and 22 Ma, but that may include older strata (Callaghan, 1938; Rowley and others, 1979, 1994, 2002; Steven and others, 1979; Cunningham and others, 1984; and Willis, 1988).

Tdv

Dipping Vat Formation (lower Oligocene to upper Eocene) – Light-gray to white, thin- to medium-bedded, fine- to medium-grained, locally coarse-grained, tuffaceous sandstone, siltstone, and mudstone exposed along the Thousand Lake fault zone east of Bicknell; mudstone is typically smectitic with a conspicuous popcorn-like weathered surface, and coarser sandstone commonly contains conspicuous biotite; upper contact is not exposed due to faulting at entrance to Sand Wash, but immediately to southeast, map unit is overlain by quartzite pebble conglomerate (Tertiary sedimentary strata, Tsl) in what may be a structural (landslide) contact; Dipping Vat strata have not been reported on the mostly covered flanks of nearby Thousand Lake Mountain nor Boulder Mountain (Doelling and Kuehne, 2007), yet its presence in the Thousand Lake Mountain fault zone suggests that the Dipping Vat Formation is indeed present, if concealed, and thus one of the principal zones of failure for large landslide complexes that blanket the flanks of these mountains; fine-grained strata are locally exposed as chaotic blocks within landslide deposits on the flanks of Thousand Lake Mountain (QTms/Tsdb) and Boulder Mountain (Qms, Qmso); we assign these beds to the Dipping Vat Formation, defined from exposures on the north flank of the Marysvale volcanic field (McGookey, 1960), but similar strata on the south flank of the field are known as the Brian Head Formation (Biek and others, 2015a, 2015b); several fission-track and K-Ar ages from the Dipping Vat Formation in the Aurora quadrangle and nearby area show it to be about 36 to 29 Ma (Willis, 1988), but the younger ages are now suspect because a U-Pb age on zircon from near the top of the unit collected in the Lost Creek area near Salina yielded an age of about 33 Ma (Willis and Doelling, 2019; UGS, unpublished data); in contrast, numerous isotopic ages on the Brian Head Formation show it to be 37 to 30 Ma (Biek and others, 2015a); east of Bicknell, these beds yielded three teeth of *Saltirius utahensis* (stingray) only known from the variegated unit of the Brian Head Formation; incomplete section about 150 feet (45 m) thick east of Bicknell; Dipping Vat strata are as much as 600 feet (180 m) thick on the north flank of the Marysvale volcanic field (Willis, 1986); Biek and others (2015b) reported that Brian Head strata at the southwestern margin of the Awapa Plateau are no more than about 1000 feet (300 m) thick in the upper reaches of Antimony Canyon, similar to its thickness on the southern Sevier Plateau southwest of this map area (Biek and others, 2015a).

Tbh **Brian Head Formation** (lower Oligocene to upper Eocene) – Mapped only in fault-bounded blocks within the Paunsaugunt fault zone Ts(Tbh) and as part of a Quaternary mass movement block Qms(Tbh), both in the southwest part of the map area; moderately to poorly resistant, light-gray, white, and light-greenish-gray, tuffaceous mudstone, siltstone, sandstone, pebbly sandstone, volcanic ash, micritic limestone, and multi-hued chalcedony; Brian Head strata are interpreted to be the main causal agent of landslide complexes along the Awapa Plateau's southwest margin, where large rotated blocks of tuffaceous mudstone and fine-grained sandstone with thin chalcedony beds, typical of Brian Head strata exposed on the southern Sevier Plateau, are present in landslide complexes below the rim of the plateau east and south of Otter Creek Reservoir (one such block is mapped separately in Antimony Canyon as Qms[Tbh]); disconformably overlain by cliff-forming tuff of Tibadore Canyon in the upper reaches of Antimony Canyon; numerous isotopic ages on the formation in the Panguitch 30' x 60' quadrangle to the southwest show it to be 37 to 30 Ma (Biek and others, 2015a); thickness unknown because lower contact with fluvial and lacustrine strata of Antimony Canyon is covered by landslides, but given outcrop constraints, must be no more than about 1000 feet (300 m) thick in the upper reaches of the canyon; just 2 miles (3 km) to the north, west of Big Point, map patterns there suggest it is no more than about 400 feet (120 m) thick; Biek and others (2015a) reported the formation to be about 1000 feet (300 m) thick on the southern Sevier Plateau southwest of the map area.

unconformity

Tsl **Tertiary sedimentary strata, lower unit** (middle Eocene? to Paleocene?) – Reddish-brown mudstone, yellowish-brown, medium- to coarse-grained "salt and pepper" sandstone, pebble conglomerate, and yellowish-brown sandy and micritic limestone; clasts are rounded, pebble- to small cobble-size quartzite of tan, gray, and white hues; contains uncommon red quartzite and rare black chert and Paleozoic limestone pebbles; typically poorly cemented and non-resistant; conglomerate is present in a small fault sliver in Crescent Canyon and southwest of Sunglow Campground where it is interpreted to be part of an old landslide mass, as a thin sliver structurally sandwiched between Dipping Vat Formation (Tdv) below and highly fractured Bullion Canyon Volcanics, undivided (Tbu), and volcanic rocks of Signal Peak (Tsp) above; similar pebbles are locally common as an unmapped lag along the length of the Thousand Lake fault zone, thus indicating the widespread presence of this unit on the covered slopes of Thousand Lake Mountain and Boulder Mountain; age and correlation uncertain, but may be related to middle Eocene (Duchesnean Land Mammal Age, about 42–38 Ma) clastic strata of Flat Top (map unit Tc of Doelling and Kuehne, 2007), which yielded a lower jaw of *Telatoceras*, a small extinct rhinoceros (DeBlieux, 2006); as much as a few tens of feet thick.

Pre-Volcanic Strata of Antimony Canyon

In the southeast part of the Marysvale volcanic field at the southwest corner of the Awapa Plateau, Antimony Canyon and Dry Wash expose an enigmatic section of fluvial, floodplain, and minor lacustrine strata more than 1000 feet (300 m) thick that bear little resemblance to strata that occupy this interval immediately north and south of the volcanic field. Smith (1957) assigned the name Flagstaff(?) Formation to these beds and discussed interpretations of earlier workers who variously assigned them to multiple Late Jurassic to Paleocene formations.

As described below, we divide this interval into four informal units and recognize that we have little age control on the lower three units. In ascending order, these units are: (1) a lower dark-reddish-brown silty sandstone and pebbly sandstone interval (TK$_1$); (2) a yellowish-brown, westward-thinning wedge of silty, fine- to medium-grained sandstone and local conglomerate with subangular to subrounded Navajo Sandstone pebbles to boulders (TK$_2$); (3) a prominent ledge-forming conglomerate interval (TKg) with rounded quartzite and limestone pebbles and cobbles; and (4) a thick, upper, "salt and pepper" sandstone and siltstone interval with several thin limestone beds (Tu). Stratigraphic studies by co-author Eaton and his students have further constrained the age and provenance of these strata, but much remains unknown. Sand of the lower three units is almost entirely well-rounded quartz recycled from Mesozoic eolianites, probably the Navajo Sandstone. Sand of the upper unit, however, contains conspicuous black chert grains and is less mineralogically mature than that of the lower units. Limestone and calcareous sandstone beds near the base of the upper unit yielded sparse early to middle Eocene gastropods, and mudstone yielded sparse early to middle Eocene palynomorphs, but the age of the lower three units remains poorly constrained. The lowest two units (TK$_1$ and TK$_2$) pinch out westward against the Antimony anticline and the third unit (TKg) is folded over the crest of the anticline; overlying, early to middle Eocene fluvial and lacustrine strata (Tu) are steeply tilted immediately adjacent to the east flank of the anticline. The lithology and structural position of the lower three units—in increasingly progressive angular unconformity over older units—is similar to North Horn strata exposed at the north edge of the volcanic field near Glenwood (Doelling and others, in preparation) and farther north in Salina Canyon (Willis, 1986) and at the south end of the San Pitch Mountains (Weiss, 1994). Collectively, the Antimony Canyon and Dry Wash strata record progressive unconformities associated with late-stage movement of the Antimony anticline. We suspect that the lower unit (TK$_1$) is correlative with the Pine Hollow Formation, well exposed southwest of Griffin Top, which is 15 miles (24 km) south of Antimony Canyon; this unit recently yielded charophyte fossils indicative of a Paleocene age (Sanjuan and others, 2020). We continue to work on the correlation of these enigmatic pre-volcanic strata.

Antimony was recovered from the sulfide mineral stibnite and its oxidation products cervantite and kermesite from small mines in sandstone beds near the lower part of the upper unit (Tu) in Antimony Canyon; small amounts of realgar and orpiment (arsenic sulfides) were also reported (Butler and others, 1920; Traver, 1949; Callaghan, 1973). Butler and others (1920) reported that the high-grade lenses of ore were discovered in 1879 and that hand-picked ore, exhausted by the early 1900s, was valued at the time at more than $100,000.

Tu **Fluvial and lacustrine strata of Antimony Canyon** (middle to lower Eocene) – Yellowish-brown to white, commonly silty, fine- to medium-grained calcareous sandstone, minor siltstone and mudstone; a thin, ledge- and cliff-forming, light-gray silty limestone occurs at and near the base in Antimony Canyon, whereas northward in Dry Wash, several thin similar limestone beds as much as about 2 feet (0.5 m) thick occur throughout the section; thin- to thick-bedded weathering to steep, ledgy slopes; includes minor thin gypsum beds and veins typically less than 1 inch (3 cm) thick; sandstone contains conspicuous black chert grains giving a "salt and pepper" appearance to many beds; no biotite or ferromagnesian minerals were identified to be part of this "pepper," therefore the map unit is considered to predate volcanism in the Marysvale field; extensively bleached with local Fe-rich Liesegang banding; mudstones are locally organic-rich and dark brown to brownish black—of five palynomorph samples, one was barren, two yielded only latest Mississippian to Early Pennsylvanian spores and pollen, and two yielded abundant latest Mississippian to Early Pennsylvanian and rare early to middle Eocene pollen—the older Paleozoic pollen is clearly reworked from unknown sources in the thrust belt (table 2); upper contact everywhere covered by landslide deposits, but map unit appears to be overlain by fine-grained tuffaceous strata of the Brian Head Formation; deposited in fluvial, floodplain, and minor lacustrine environments; sparse gastropods indicate an early to middle Eocene age for the basal part of the Tu map unit (Joseph Hartman, University of North Dakota, written communication, February 9, 2015), as do rare palynomorphs; a U-Pb detrital zircon analysis of sample A072514-1, from the base of the section in Dry Wash, yielded a single 37.6 ± 3.1 Ma grain (not enough to base an age on) and a prominent middle Cretaceous peak (UGS and O'Sullivan, 2017); maximum exposed thickness about 800 feet (240 m).

TKu **Cretaceous-Tertiary strata, undivided** (lower Eocene to Upper Cretaceous) – Map units TK$_1$, TK$_2$, and TKg undivided on the south side of Dry Wash due to map scale.

TKg **Conglomerate unit** (lower Eocene to Upper Cretaceous) – Yellowish-brown, thick-bedded, cliff-forming conglomerate and, especially near the middle of the unit, minor interbedded, medium- to coarse-grained sandstone lenses; clasts are rounded Paleozoic limestone, quartzite, chert, and minor Navajo Sandstone as much as 6 inches (15 cm) in diameter; sand is almost entirely rounded quartz, probably recycled from the Navajo Sandstone; extensively bleached with local iron-rich Liesegang banding; upper contact corresponds to the top of the conglomerate cliff, above which is a thin sandstone interval with abundant chert grains and an overlying thin carbonate interval; angularly unconformable over the Antimony anticline where it was folded during late-stage development of that structure; deposited in a fluvial environment; appears to locally pinch out in an unnamed drainage immediately east of an abandoned mill on the south side of Antimony Canyon, but is typically 150 to 200 feet (45–60 m) thick.

TK$_2$ **Sandstone and conglomerate unit** (lower Eocene to Upper Cretaceous) – Yellowish-brown, typically medium- to thick-bedded, calcareous, fine- to medium-grained silty sandstone and conglomerate; conglomerate is composed of subangular to subrounded pebbles to boulders of locally derived Navajo Sandstone and minor rounded chert pebbles; this conglomerate forms the base of the unit in eastern exposures, as well as several overlying thin beds typically 3 to 5 feet (1–2 m) thick throughout the remainder of the unit, but is locally missing westward towards the Antimony anticline; includes minor thin gypsum layers and veins typically less than 1 inch (3 cm) thick; sand is almost entirely rounded quartz, probably recycled from the Navajo

Sandstone; extensively bleached with common iron-rich Liesegang banding in sandstone beds; weathers to ledgy slopes; upper contact corresponds to the base of the overlying cliff-forming quartzite conglomerate; deposited in fluvial and floodplain environments; as much as about 400 feet (120 m) thick in eastern Antimony Canyon, but thins dramatically westward towards the Antimony anticline where it is no more than a few tens of feet thick and where it is absent over the crest of the anticline.

TK_1 **Lower unit** (lower Eocene to Upper Cretaceous) – Dark-reddish-brown to dark-reddish-purple, calcareous, fine- to medium-grained silty sandstone and siltstone with floating chert shards and rounded chert pebbles; also includes thin, typically 1- to 2-foot-thick (<1 m) lenses of chert pebble conglomerate and minor thin gypsum layers and veins typically less than 1 inch (3 cm) thick; sand is almost entirely rounded quartz, probably recycled from the Navajo Sandstone; lower part in Antimony Canyon includes several thin beds of purplish smectitic mudstone with carbonate nodules; secondary alteration has locally bleached the upper part of the map unit to yellowish brown and this color change cuts across bedding, first observed by Smith (1957); upper part typically forms prominent, massive weathering, fluted cliff and badland slopes; upper contact corresponds to the base of ledge-forming, yellowish-brown, quartzose sandstone, silty sandstone, and conglomerate composed of subangular to subrounded Navajo Sandstone pebbles and boulders; deposited in fluvial and floodplain environments; mostly equivalent to Smith's (1957) unit "A" for which he reported a maximum thickness of 297 feet (90 m); as mapped here, an incomplete section of the unit is as much as 200 feet (60 m) thick, but thins westward to about 100 feet (30 m) thick immediately east of Antimony anticline, and is absent over the crest of the anticline.

K unconformity

JURASSIC

Je **Entrada Sandstone** (Middle Jurassic) – Pale- to light-brown, fine-grained sandstone and silty sandstone that weathers to steep slopes; indistinctly bedded but with local ripple cross-stratification; lower part contains minor secondary gypsum veins; exhibits local reduced zones and spots that are light gray; deposited in tidal-flat, sabkha, and coastal-dune environments (Peterson, 1988, 1994); incomplete section of a fault-bounded block southwest of Black Ridge is about 245 feet (75 m) thick; Doelling and Kuehne (2007) reported that it is 650 to 800 feet (200–245 m) thick in the east half of the Loa 30' x 60' quadrangle.

Jc **Carmel Formation** (Middle Jurassic) – Undivided in a fault block along the Thousand Lake fault zone north of Bicknell and on cross sections.

The northeast part of the map area near Bicknell lies near the northern end of a region of extensive sand influx during the Middle Jurassic stretching from north-central Arizona into south-central Utah, which created complex and intertonguing relations between shallow-marine, tidal-flat, and fluvial-eolian deposition of the Carmel and Temple Cap Formations (Doelling and others, 2013). Carmel Formation nomenclature of Sprinkel and others (2011a) and Doelling and others (2013) is used in this map. The Carmel Formation was deposited in a shallow sea of a back-bulge basin and, together with the underlying Temple Cap Formation, provides the first clear record of the effects of the Sevier orogeny in southwest Utah (Sprinkel and others, 2011a; Phillips and Morris, 2013). Middle Jurassic age is from Imlay (1980), Sprinkel and others (2011a), and Doelling and others (2013). Thicknesses are from an unpublished measured section by Douglas Sprinkel and Hellmut Doelling (Utah Geological Survey, written communication, 2015). Pipiringos and O'Sullivan (1978) interpreted that Temple Cap and Carmel strata were separated by their J-2 unconformity, but new radiometric ages and palynomorph data suggest that the J-2 does not exist or is a very short hiatus in southern Utah (Sprinkel and others, 2011a; Doelling and others, 2013).

Jcu **Winsor and Paria River Members, undivided** (Middle Jurassic, Callovian to Bathonian) – Undivided on the southern Aquarius Plateau following Weir and others (1990) and Doelling and Willis (2018); as much as about 100 feet (30 m) thick in this map area.

Jcw **Winsor Member** (Middle Jurassic, Callovian to Bathonian) – Along the north half of the Waterpocket Fold immediately east of this map area, Winsor strata are divided into a lower gypsiferous subunit and a thicker upper banded subunit, described separately below; mapped as undivided in fault blocks along Thousand Lake fault zone and in Antimony Canyon, where it is non-resistant, light-reddish-brown or locally greenish-gray, laminated shale, siltstone, and fine- to medium-grained sandstone, all with thin gypsum beds and cross-cutting veins; poorly cemented and so weathers to vegetated slopes; upper, conformable contact placed at the top of the highest thin gypsum ledge and at the base of massive weathering, paleto light-brown, fine-grained sandstone of the Entrada Sandstone, but in Antimony Canyon upper contact is unconformable at the base of a dark-reddish-brown pebbly sandstone and conglomerate of uncertain but likely Late Cretaceous to early Eocene age (TK_1); deposited on a broad, sandy mud flat (Imlay, 1980; Blakey and others, 1983); incomplete section south of Bicknell is over 200 feet (60 m) thick, and an overturned section in Antimony Canyon is a few tens of feet thick.

Jcwb **Banded subunit** (Callovian to Bathonian) – Interbedded, mostly light-gray, yellowish-gray, greenish-gray, and minor reddish-brown siltstone, mudstone, and fine-grained sandstone, and numerous, thin (<3 feet [1 m] thick), white alabaster gypsum beds; thin, cross-cutting gypsum veins are common; mostly non-resistant and slope forming except for thin gypsum ledges; upper, conformable contact placed at the top of the highest thin gypsum ledge and at the base of massive weathering, pale- to light-brown, fine-grained sandstone of the Entrada Sandstone; nearly complete section of subunit is 404 feet (123 m) thick on Black Ridge (Douglas Sprinkel, written communication, May 14, 2015), and Doelling and Kuehne (2007) reported that it thins eastward from 450 to 120 feet (137–37 m) thick in the east half of the Loa 30' x 60' quadrangle.

Jcwg **Gypsiferous subunit** (Bathonian) – Thick alabaster gypsum beds as much as several tens of feet thick and interbedded, thin- to medium-bedded, reddish-brown and light-gray siltstone, mudstone, fine-grained sandstone and, below an uppermost thick limestone bed, light-gray, laminated, micritic to finely crystalline silty limestone; forms ledgy slopes; upper contact is conformable and gradational and corresponds to the top of the highest thick (> 3 feet [1 m]) gypsum bed; subunit is 229 feet (70 m) thick on Black Ridge (Douglas Sprinkel, written communication, May 14, 2015), and Doelling and Kuehne (2007) reported that it thins eastward from 230 to 80 feet (70–24 m) thick in the east half of the Loa 30' x 60' quadrangle.

Jcp **Paria River Member** (Middle Jurassic, Bathonian) – Light-gray, greenish-gray, yellowish-gray, and minor reddish-brown, thin- to medium-bedded, fine-grained sandstone, siltstone, and mudstone, minor light-gray, micritic to finely crystalline, chippy-weathering limestone, and numerous thick white alabaster gypsum beds including a 31-foot-thick (10 m) bed at the base of the member; upper contact corresponds to the top of a bench-forming, yellowish-gray sandy limestone or fine-grained calcareous sandstone; deposited in shallow-marine and coastal-sabkha environments during the second major transgression of the Middle Jurassic seaway (Imlay, 1980; Blakey and others, 1983); Sprinkel and others (2011a) reported an $^{40}Ar/^{39}Ar$ age on zircon from a volcanic ash of 165.9 ± 0.51 Ma on lower Paria River strata in south-central Utah; 211 feet (64 m) thick on Black Ridge (Douglas Sprinkel, written communication, May 14, 2015), and Doelling and Kuehne (2007) reported that it thins eastward from 220 to 100 feet (67–30 m) thick in the east half of the Loa 30' x 60' quadrangle.

As mapped southeast of Bicknell, near Sunglow Campground, the base of the member is placed at the base of a ridge-forming, light-gray, sandy limestone and calcareous mudstone capped by a 3- to 6-foot-thick (1–3 m), yellowish-brown, fine- to coarse-grained sandy limestone with subrounded, brown and gray chert grains 1 to 3 mm in diameter; this unusual, coarse sandstone interval is in turn overlain by a few tens of feet of light-gray to grayish-brown calcareous mudstone and fine- to medium-grained sandstone with local coarse grains of subrounded black chert; in that area, the remaining Carmel is apparently cut out by faulting.

In Antimony Canyon, Paria strata are resistant, light- and yellowish-gray micritic and argillaceous limestone and calcareous mudstone laminated in very thick beds, minor reddish-brown and greenish-gray shale, and, at the base of the member, a thick gypsum bed. There, Paria strata are vertical and as much as 230 feet (70 m) thick but may be structurally attenuated.

Jcl **Crystal Creek and Co-op Creek Limestone Members, undivided** (Middle Jurassic, Bathonian to Bajocian) – Combined unit due to map scale limitations; in excess of 200 feet (60+ m) thick; members described separately below.

Jcx **Crystal Creek Member** (Middle Jurassic, Bathonian) – Non-resistant, thin- to medium-bedded, reddish-brown and yellowish-brown siltstone and fine-grained sandstone; upper contact typically corresponds to the base of a thick, white, nodular Paria River gypsum bed; as mapped southeast of Bicknell, near Sunglow Campground, the middle part of the member includes a channel-form, 10-foot-thick (3 m), light-gray to yellowish-brown, intraformational pebble conglomerate with subrounded calcareous sandstone rip-up clasts as much as 3 inches (8 cm) in diameter; Kowallis and others (2001) reported two ^{40}Ar/^{39}Ar ages of 166 to 167 Ma for altered volcanic ash beds (that were likely derived from a magmatic arc in what is now southern California and western Nevada) within the member near Gunlock, Utah, and Doelling and others (2013) reported an average ^{40}Ar/^{39}Ar age on sanidine of 167.1 ± 0.70 Ma and an average U-Pb age on zircon of 165.7 ± 1.0 Ma for several ash beds in the coeval Thousand Pockets Member in south-central Utah; deposited in coastal-sabkha and tidal-flat environments during the first major regression of the Middle Jurassic seaway (Imlay, 1980; Blakey and others, 1983); 30 feet (9 m) thick on Black Ridge (Douglas Sprinkel, written communication, May 14, 2015).

In Antimony Canyon, Crystal Creek strata are non-resistant, thin- to medium-bedded, reddish-brown siltstone, mudstone, and fine- to medium-grained sandstone that are commonly gypsiferous and locally contain contorted pods of gypsum. The upper contact corresponds to the base of the thick Paria River gypsum bed. Crystal Creek strata are as much as 150 feet (45 m) thick in Antimony Canyon, but may be structurally attenuated.

Jcc **Co-op Creek Limestone Member** (Middle Jurassic, Bajocian) – Thin- to medium-bedded, light-gray, light-olive-gray, yellowish-brown, and minor reddish-brown micritic limestone, sandy limestone, calcareous, fine- to medium-grained sandstone, siltstone, and calcareous shale; locally fossiliferous with *Isocrinus* sp. crinoid columnals, pelecypods, and gastropods, including a laterally persistent 1- to 2-foot-thick (0.3–0.6 m) coquina located about 10 feet (3 m) above the base of the member; upper contact corresponds to the top of a ledge-forming, brownish-gray sandy limestone with pelecypod fossil hash, above which lies slope-forming, reddish-brown siltstone; as mapped southeast of Bicknell, the middle part of the member includes a reddish-brown siltstone and fine-grained sandstone interval not present at Black Ridge; Kowallis and others (2001) reported several ^{40}Ar/^{39}Ar ages of 167 to 168 Ma for altered volcanic ash beds within the lower part of the member in southwest Utah that were likely derived from a magmatic arc in what is now southern California and western Nevada; Sprinkel and others (2011a) also reported ^{40}Ar/^{39}Ar ages of 169.2 ± 0.51 Ma and 169.9 ± 0.49 Ma on two ash beds in the lower part of the member in southwest Utah; deposited in a shallow-marine environment during the first major transgression of the Middle Jurassic seaway (Imlay, 1980; Blakey and others, 1983); 119 feet (36 m) thick on Black Ridge, of which the upper 66 feet (20 m) is equivalent to the Rich Member of the Twin Creek Limestone and the lower 53 feet (16 m) is equivalent to the Slide Rock Member (Douglas Sprinkel, written communication, May 14, 2015).

In Antimony Canyon, Co-op Creek Limestone strata are resistant, thin- to medium-bedded, light-gray micritic limestone and calcareous shale, locally with *Isocrinus* sp. crinoid columnals, pelecypods, and gastropods. These strata differ considerably from the lower Carmel southeast of Bicknell, as they lack interbedded sandstone and siltstone (thus they resemble basal Carmel exposures of southwest Utah rather than the time-equivalent Judd Hollow Member of the Henry Mountains basin). The upper contact corresponds to the base of slope-forming reddish-brown siltstone. Co-op Creek strata are as much as about 400 feet (120 m) thick in Antimony Canyon but may be structurally attenuated.

Jtc **Thousand Pockets and Judd Hollow Members of Carmel Formation and Temple Cap Formation, undivided** (Middle Jurassic) – Mapped at the southern map border south of Burr Top. The following description is from Doelling and Willis (2018); consists of three generally thin units that are combined for mapping: (descending) Thousand Pockets Member of Carmel Formation, Judd Hollow Member of Carmel Formation, and Temple Cap Formation (Doelling and others, 2013); Thousand Pockets Member is light-gray-orange, fine- to medium-grained, cross-bedded sandstone, 0 to 80 feet (0–24 m) thick; Judd Hollow Member is chiefly red-brown siltstone or mudstone, commonly contorted fine-grained sandstone, and light-gray, thin-bedded limestone 0 to 110 feet (0–33 m) thick, pinching out to south and east; Temple Cap Formation is light-gray-orange, cross-bedded, fine-grained sandstone with small chert pebbles at base, rests unconformably on Navajo Sandstone, and is 10 to 120 feet (3–37 m) thick where exposed, generally thickening westward; entire map unit is 60 to 230 feet (18–70 m) thick.

Jtm **Temple Cap Formation, Manganese Wash Member** (Middle Jurassic) – Reddish-brown, yellowish-orange, yellowish-gray, and yellowish-brown, thin-bedded, fine- to medium-grained quartzose sandstone and minor siltstone; sandstone is typically coarser and more poorly sorted than that of the Navajo Sandstone and locally contains coarse grains; weathers to thin ledges and slopes; overall, lower half is yellowish brown and upper half is reddish brown; upper contact is at the base of a 3-foot-thick (1 m) ledge of yellowish-brown, fine-grained sandy limestone; based on $^{40}Ar/^{39}Ar$ ages of sanidine and biotite, and on U-Pb zircon ages, the preferred age of Temple Cap strata is 172.9 ± 0.6 to 170.2 ± 0.5 Ma (Sprinkel and others, 2011a); 43 feet (13 m) thick on Black Ridge (Douglas Sprinkel, written communication, May 14, 2015) and thins to the north.

The Bicknell quadrangle lies along the east flank of an early Middle Jurassic paleohigh of the Navajo Sandstone, which likely formed during development of the regional J-1 unconformity (Doelling and others, 2013; Phillips and Morris, 2013). Temple Cap strata thin or are locally absent over this paleohigh, showing that erosional development of the J-1 unconformity later influenced sedimentation during Temple Cap time. Temple Cap strata are not present on much of the Waterpocket Fold, and they are also missing on the vertical, east limb of the large anticline exposed at the entrance to Antimony Canyon, possibly due to the area's location near the axis of this paleohigh or possibly due to attenuation associated with folding in the core of the anticline.

J-1 unconformity (Pipiringos and O'Sullivan, 1978) formed prior to 173 million years ago in southwest Utah (Sprinkel and others, 2011a).

Jn **Navajo Sandstone** (Lower Jurassic) – Massively cross-bedded, moderately well-cemented, pale-reddish-orange and light-gray or white sandstone that consists of well-rounded, fine- to medium-grained, frosted quartz sand; upper half is white on Black Ridge, whereas on the southwest flank of Thousand Lake Mountain only the middle part of the formation is white, in both areas due to alteration, remobilization, and bleaching of limonitic and hematitic (iron-bearing) cement, probably due to hydrocarbon migration (see, for example, Chan and others, 2000; Beitler and others, 2003; Potter and Chan, 2011); bedding consists of high-angle, large-scale cross-bedding in tabular planar, wedge planar, and trough shaped sets 10 to 45 feet or more (3–14+ m) thick; ironstone bands and concretions are locally common; prominently jointed due to position on northwest-plunging nose of the Waterpocket Fold and proximity to the Thousand Lake Mountain fault zone, thus weathers to steep rounded knobs and slopes, unlike its typical sheer cliffs; upper, unconformable contact is the J-1 regional unconformity, corresponding to a prominent break in slope, with cross-bedded sandstone below in steep and ledgy slopes of reddish-brown, thin-bedded sandstone and siltstone of the Manganese Wash Member of the Temple Cap Formation above; deposited in a vast coastal and inland dune field with prevailing winds principally from the north (Blakey, 1994; Peterson, 1994), part of one of the world's largest coastal and inland paleodune fields (Milligan, 2012); correlative in part with the Nugget Sandstone of northern Utah and Wyoming and the Aztec Sandstone of southern Nevada and adjacent areas (see, for example, Kocurek and Dott, 1983; Riggs and others, 1993; Sprinkel and others, 2011b); much of the sand may originally have been transported to areas north and northwest of Utah via a transcontinental river system that tapped Grenvillian-age (about 1.0 to 1.3 Ga) crust involved in Appalachian orogenesis of eastern North America (Dickinson and Gehrels, 2003, 2009a, 2009b; Rahl and others, 2003; Reiners and others, 2005); map patterns show that the Navajo is about 800 feet (245 m) thick on the southwest flank of Thousand Lake Mountain, and Doelling and Kuehne (2007) reported that the formation is 800 to 1100 feet (240–330 m) thick in the adjacent east half of the Loa 30' x 60' quadrangle; Smith (1957) reported 1650 feet (500 m) of Navajo Sandstone in Antimony Canyon, but map patterns there suggest an incomplete thickness of about 1150 feet (350 m).

Jk **Kayenta Formation** (Lower Jurassic) – Moderate- to dark-reddish-brown, thin- to thick-bedded, fine-grained sandstone and siltstone, and minor mudstone, thin algal-laminated limestone beds, and scattered lenses of intraformational conglomerate with mudstone and siltstone rip-up clasts; planar, low-angle, and ripple cross-stratification is common; upper part was mapped by Doelling and Kuehne (2007) as the "lower tongue" of the Navajo Sandstone, thus including an interval of mostly sandstone 110 to 150 feet (34–46 m) thick, but because this sandstone interval apparently thins westward and becomes less prominent, we prefer to place the upper contact at the stratigraphically highest siltstone interval; forms steep ledgy slope, and, near the top, a broad bench; upper contact is conformable and gradational and corresponds to the top of the highest thin siltstone and mudstone beds, above which is the massively cross-bedded Navajo Sandstone; deposited in river and minor lacustrine environments, although a thick eolian tongue of the Navajo Sandstone, east of the map area, is present in the upper part of the formation (Smith and others, 1963; Friz, 1980; Blakey, 1994; Peterson, 1994; Doelling and Kuehne, 2007); paleocurrent studies at Capitol Reef National Park show that Kayenta streams flowed towards the west in the lower and upper parts of the formation, but that the middle part of the formation is dominantly eolian with winds that blew from west to east (Friz, 1980); map patterns show that as defined here the Kayenta is about 200 feet (60 m) thick on the southwest flank of Thousand Lake Mountain; Doelling and Kuehne (2007) reported that the formation (not including their tongue of the Navajo Sandstone [Jnl]) is 150 to 220 feet (45–67 m) thick in the adjacent east half of the Loa 30' x 60' quadrangle.

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JŦRw **Wingate Sandstone** (Lower Jurassic to Upper Triassic) – Reddish-brown, light-brown, and pale-reddish-orange, massively cross-bedded, moderately well-cemented, fine-grained sandstone that consists of well-rounded, frosted quartz sand; prominently jointed due to position on northwest-plunging nose of the Waterpocket Fold and proximity to the Thousand Lake Mountain fault zone, thus weathers to steep rounded knobs and slopes, unlike its typical sheer cliffs; upper contact is gradational over several tens of feet and corresponds to the base of the lowest reddish-brown siltstone and mudstone interval; sand was deposited principally from winds out of the northwest (Stewart and others, 1959); basal Wingate strata are Triassic based on fossil trackways (Lockley and others, 2004; Lucas and others, 2005) and paleomagnetic data (Molina-Garza and others, 2003); map patterns show that the Wingate is about 250 feet (75 m) thick on the southwest flank of Thousand Lake Mountain; Doelling and Kuehne (2007) reported that the formation is 300 to 400 feet (90–120 m) thick in the adjacent east half of the Loa 30' x 60' quadrangle, although Sorber and others (2007) reported a thickness of 260 to 310 feet (80–95 m) on the southwest flank of the Fruita anticline in the Twin Rocks quadrangle.

unconformity

TRIASSIC

ŦRu **Chinle and Moenkopi Formations, undivided** (Lower to Upper Triassic) – Fault slivers of Chinle and Moenkopi red beds at the entrance to Antimony Canyon; exposed thickness as much as several tens of feet.

ŦRc **Chinle Formation, undivided** (Upper Triassic, Norian and Rhaetian) – Locally mapped as undivided in fault blocks along the Thousand Lake fault zone southeast of Bicknell, and also used on cross section. The Chinle Formation was deposited in a variety of fluvial, floodplain, palustrine, and lacustrine environments of a back-arc basin formed inland of a magmatic arc associated with a subduction zone along the west coast of North America; resistant, locally conglomeratic sandstones, including the Shinarump Member, were deposited in braided and meandering streams that flowed north and northwest, whereas mudstone intervals were deposited in floodplains, lakes, and swamps (e.g., Stewart and others, 1972a; Blakey and Gubitosa, 1983, 1984; Lucas, 1993; Dubiel, 1994; Lucas and Tanner, 2007; Dubiel and Hasiotos, 2011). Chinle strata are among the most productive for fossilized continental plants and vertebrates in the world (Benton, 1995). Kirkland and others (2014) reported fossil conifers, giant horsetails, ferns, conchostrachans (clam shrimp), bivalves, and a variety of vertebrates including lungfish, metoposaurids (primitive amphibian), phytosaurs (crocodile-like reptiles), and aetosaurs (armored terrestrial animals) from nearby Capitol Reef National Park. Swelling, smectitic mudstone and claystone are common in the Chinle and, although typically poorly exposed, their bright purple, grayish-red, dark-reddish-brown, light-greenish-gray, brownish-gray, olive-gray, and similar hues locally show through to the surface—these clay-rich beds weather to a "popcorn" surface and are responsible for numerous building foundation problems and landslides across its outcrop belt. The Chinle Formation represents a span of about 25 million years, from about 228 to 203 Ma, during the Late Triassic (Irmis and others, 2011; Ramezani and others, 2011, 2014). Kirkland and others (2014) provided a comprehensive summary of the formation at nearby Capitol Reef National Park where they recognized five members; from oldest to youngest these are the Shinarump, Monitor Butte, Moss Back, Petrified Forest, and Owl Rock Members (the Church Rock Member, commonly the uppermost member throughout the region, is not recognized in the Capitol Reef area). Collectively, Chinle strata thicken southward along the Waterpocket Fold, from 404 feet (123 m) near Chimney Rock to 528 feet (161 m) near Burr Trail (Kirkland and others, 2014).

ŦRcu **Chinle Formation, upper slope former (Owl Rock Member and upper part of the Petrified Forest Member)** (Upper Triassic) – Combined unit here due to map scale limitations and difficulty in placing member contact. The **Owl Rock Member** is reddish-brown, greenish-gray, and grayish-red, commonly mottled, fine- to medium-grained sandstone, siltstone, and mudstone that weathers to steep ledgy slopes mostly covered by talus derived from the Wingate Sandstone. The upper part of the **Petrified Forest Member** is similarly colored mudstone, siltstone, and fine-grained sandstone that weathers to slopes and is gradationally overlain by the Owl Rock Member. Upper, unconformable contact of combined unit is at the base of a thin, mottled, reddish-brown and greenish-gray, fine-grained pebbly sandstone with mudstone rip-up clasts, above which is the massive, moderate-reddish-orange, eolian sandstone of the Wingate (Kirkland and others, 2014). In the east half of the Loa 30' x 60' quadrangle, this combined unit is 140 to 220 feet (43–67 m) thick (Doelling and Kuehne, 2007); Martz measured 26 feet (7.8 m) of upper Petrified Forest strata and 125 feet (38.2 m) of Owl Rock strata near Chimney Rock in Capitol Reef National Park (Kirkland and others, 2014); map patterns show that the upper slope-forming part of the Chinle as mapped here is about 130 feet (40 m) thick in the Rock Canyon area southeast of Bicknell.

ŦRcl **Chinle Formation, lower slope former (lower Petrified Forest Member and Mossback Member)** (Upper Triassic) – Combined unit here due to map scale limitations and difficulty in placing member contact. Lower part of the **Petrified Forest Member** is variably colored and commonly mottled, reddish-brown, yellowish-brown, grayish-red, and greenish-gray mudstone, siltstone, and minor fine-grained sandstone; includes numerous, thick, mottled paleosols with common greenish-gray carbonate nodules; weathers to rounded slopes below a thin sandstone ledge of the informally named Capitol Reef bed, a ledge-forming, fine- to coarse-grained sandstone and pebbly sandstone with mudstone rip-up clasts that is commonly fossiliferous and 15 to 23 feet (4.7–7 m) thick on the Waterpocket Fold (Kirkland and others, 2014). **Mossback Member** is reddish-brown to grayish-brown, thin- to medium-bedded, medium- to coarse-grained sandstone, locally with mudstone rip-up clasts and petrified wood; typically forms ledge and is gradationally overlain by the Petrified Forest Member. Upper contact as mapped here is placed at an abrupt change in slope at the top of the Capitol Reef bed. In the east half of the Loa 30' x 60' quadrangle, this combined unit is 90 to 190 feet (27–58 m) thick, but some of that variation may be due to the difficulty in placing the lower contact (Doelling and Kuehne, 2007); Martz measured 20 feet (6 m) of Mossback strata and 63 feet (19.2 m) of overlying Petrified Forest strata near Chimney Rock in Capitol Reef National Park (Kirkland and others, 2014); map patterns show that the lower slope-forming part of the Chinle as mapped here is about 210 feet (65 m) thick in the Rock Canyon area southeast of Bicknell.

ŦRcm **Chinle Formation, Monitor Butte Member** (Upper Triassic) – Mudstone and sandstone of predominantly gray and greenish-gray hues, with subordinate reddish-brown and yellowish-brown colors; commonly mottled and variegated; sandstone is typically fine to medium grained, rarely coarse grained, and is locally conglomeratic with mudstone rip-up clasts and local petrified wood; dark-yellowish-orange and grayish-orange carbonate nodules, indicative of paleosols, are abundant in the uppermost part of the member; forms rounded slopes; upper gradational contact corresponds to the base of reddish-brown, thin- to medium-bedded, fine- to coarse-grained sandstone and pebbly sandstone with mudstone rip-up clasts of the more resistant Mossback Member; in the east half of the Loa 30' x 60' quadrangle, the Monitor Butte Member is 110 to 190 feet (34–58 m) thick (Doelling and Kuehne, 2007); Martz measured 132.5 feet (40.4 m) of Monitor Butte strata near Chimney Rock in Capitol Reef National Park, although the lower part is deformed and thus of uncertain thickness, and noted that the member thickens southward on the Waterpocket Fold (Kirkland and others, 2014); map patterns show that Monitor Butte strata are about 110 feet (33 m) thick in the Rock Canyon area southeast of Bicknell.

ŦRcs **Chinle Formation, Shinarump Member** (Upper Triassic, lower Norian) – Yellowish-brown, fine- to coarse-grained sandstone and minor pebbly sandstone that forms a prominent cliff; clasts are subrounded quartz, quartzite, and chert; locally contains minor gray to greenish-gray siltstone and mudstone lenses; medium- to thick-bedded with both planar and low-angle cross-stratification and common scour and fill structures; locally contains petrified logs, especially in the upper part; important uranium host (Stewart and others, 1972a); regionally, upper contact is gradational and interfingering (Stewart and others, 1972a), but it is erosional on the Waterpocket Fold where Beer (2005) interpreted it as a sequence stratigraphic boundary (see also Kirkland and others, 2014); age from the likely correlative Mesa Redondo Member of northern Arizona (Ramezani and others, 2014); Kirkland and others (2014) reported that the thickness of Shinarump strata differs considerably along the Waterpocket Fold due less to deposition in paleovalleys (as is typical elsewhere on the Colorado Plateau) than to pre-Monitor Butte Member erosion; in the east half of the Loa 30' x 60' quadrangle, the Shinarump Member is 0 to 145 feet (0–44 m) thick (Doelling and Kuehne, 2007); the Shinarump Member is about 40 feet (12 m) thick in the Rock Canyon area southeast of Bicknell.

TR-3 unconformity (Pipiringos and O'Sullivan, 1978), a widespread episode of erosion across the western U.S. that spans about 10 Myr during late Middle and early Late Triassic time (e.g., Kirkland and others, 2014).

Ꞧm **Moenkopi Formation, undivided** (Lower to Middle Triassic) – Shown on cross section only; in the east half of the Loa 30' x 60' quadrangle, the Moenkopi Formation thickens westward from 625 to 990 feet (190–300 m) (Doelling and Kuehne, 2007).

Ꞧmm **Moenkopi Formation, Moody Canyon Member** (lower Middle Triassic) – Reddish-brown, thin- to medium-bedded and laminated siltstone and fine-grained sandstone; commonly ripple laminated and siltstone is commonly micaceous; contains gypsum veinlets and thin beds; forms steep cliff and slope below the Shinarump Member; upper contact is a pronounced unconformity and corresponds to the base of yellowish-brown, medium- to coarse-grained sandstone and pebbly sandstone of the Shinarump Member; deposited in tidal flat environment on a low-relief continental shelf (Stewart and others, 1972b; Dubiel, 1994); probably Anisian (early Middle Triassic) on the Waterpocket Fold (Lucas and Schoch, 2002); in the east half of the Loa 30' x 60' quadrangle, the Moody Canyon Member of the Moenkopi Formation thickens westward from 260 to 425 feet (80–130 m) thick, whereas the entire Moenkopi Formation thickens westward from 625 to 990 feet (190–300 m) thick (Doelling and Kuehne, 2007); map patterns show that an incomplete section of the Moody Canyon Member is about 230 feet (70 m) thick near where the Fremont River exits the quadrangle.

P **PERMIAN** – Undivided on cross section.

IP **PENNSYLVANIAN** – Undivided on cross section.

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